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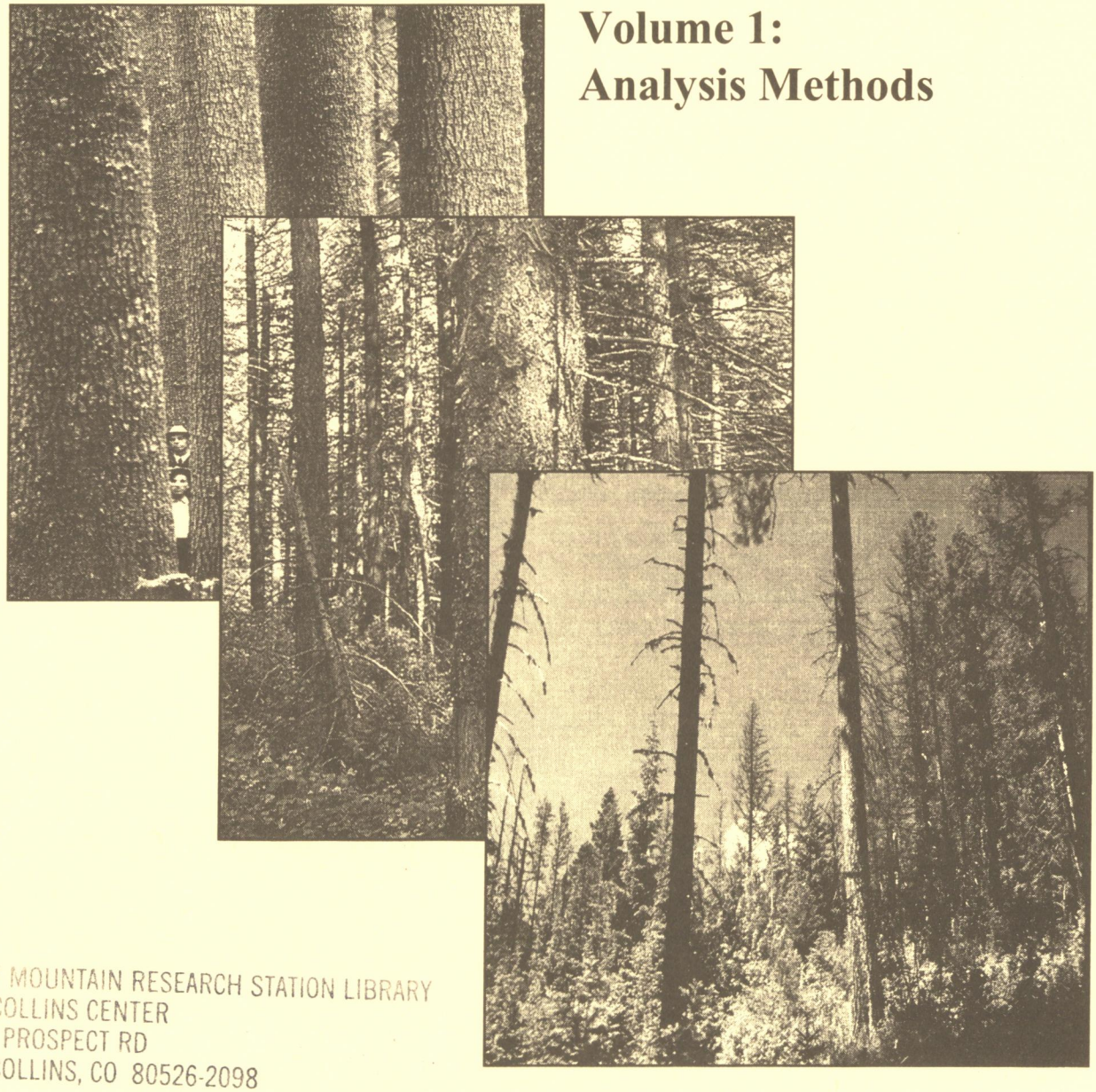
Succession Functions of Pathogens and Insects

Ecoregion Sections M332a and M333d in Northern Idaho and Western Montana



Volume 1: Analysis Methods

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On the cover:

Pathogen and insect succession functions at work through time.

Mountain pine beetle was an important native insect in mature white pine forests (upper-left photograph). With the introduction of the exotic white pine blister rust fungus, white pines were no longer able to survive in great numbers and their place was filled, in large part, by Douglas-fir and grand fir (middle photograph). These forests, in turn, became hosts to epidemics of bark beetles and root diseases. In the aftermath of these epidemics, some forests have been maintained in conditions of perpetually young trees that die from root disease before reaching maturity (lower-right photograph).

Succession Functions of Forest Pathogens and Insects

Ecosections M332a and M333d in
Northern Idaho and Western Montana.

Volume 1: Methods

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SECTION 1: INTRODUCTION

THE ANALYSIS

Although the forests of North America have become far less "continuously distributed" and far more "anthropogenically influenced" than in the early days of succession analysis, pathogens and insects were probably then, as they are now, the primary and most predictable agents of change. Pathogens and insects recycle more biomass than is typically consumed by fires in even the most fire-intensive ecosystems. Most of the outcomes of activities of pathogens and insects are so integral to the rates and trends of vegetation succession as to be indistinguishable from the process of succession. Two of the most common functions resulting from insect and pathogen actions in northern Idaho and western Montana are: 1) a slowing of the pace at which early-seral species such as ponderosa pine and western larch are replaced by more shade- or competition-tolerant species, or 2) acceleration of the pace at which climax composition and structures are reached. In application, it is fairly impossible to clearly distinguish between the so-called "disturbance functions" of pathogens and insects and their activities that affect the course and timing of succession. There are dramatic actions, such as the mountain pine beetle outbreaks of the 1970s, that would seem easily recognized as disturbances; but rather than reset the successional time, as fires often do, the most common function of the beetle outbreak has been to accelerate the rate at which sites converted to climax subalpine fir or grand fir compositions.

It is important not to lose sight of the fact that succession is not restricted to the vegetative components of forest communities. Even structural stages–referred to as "successional stages" in Harris' "The Fragmented Forest" (Harris 1984)–are difficult to predict if we attempt to map changes in the absence of significant insect and pathogen influences. What causes a stand of trees to lose canopy closure? At what rate, without pathogens and insects? In addition to structural stage changes, there are changes in species composition through time. There are often a number of alternative pathways and a range of rates of change in both structure and composition. Since these changes do not take place in the absence of pathogens and insects, it is of only academic interest to estimate changes in the absence of pathogens and insects.

For the purpose of this analysis, we have recognized two terms which help us describe effects of pathogens and insects in forest ecosystems. One such term is *silvical succession*. We use this term to refer to changes in tree species composition and structure that result from the autecology (relating to site conditions) and synecological interaction among the trees themselves with little influence from pathogens, insects, fires, or human activities. Silvical succession does not preclude windfall, ice, or snow damage, or other, usually fine-grained, disturbance effects. For the most part, silvical succession is attributable to the relative tolerance of species to lateral competition and shading, seed production, and the regeneration requirements of species. We also conceptually recognize "seral" and "climax" roles of species as related to site habitat types (Daubenmire 1952). That the process of succession is not an orderly march toward climax is evident in the results of this and other analyses (Oliver 1981, Cook 1996). While we agree with Mueller-Dombois and Ellenberg's (1974) assessment that a number of potential climax community types are possible within a climatic region. These take the form of edaphic climax types, topographic climax types, and so on. While some of this variation is captured in the habitat type and series classification systems, only the one or two most predictable members of the climax community may be present. Also, because of periodic or constant disturbances, the

potential climax communities indicated by habitat type may be rare or absent from real landscapes, with succession seldom progressing to climax and the potentially "stable" climax communities typically subject to disturbances. Nonetheless, we find the concept useful in assessing the potential changes composition and structure in the absence of specific disturbances. These changes indicate a trend toward climax rather than the climax itself (Pfister and Arno 1980).

Pathogen and Insect Succession Function: The outcome of specific actions of pathogens and insects which alter the course or timing of succession.

The part of the variability in succession that is probably due to the actions of pathogens and insects depends mostly on site and host conditions. In this analysis, we examine the relationship between actions of pathogens and insects and the course and timing of succession. In this way, we identify the succession functions of pathogens and insects.

Pathogens and insects are the primary recycling agents in most forests. In forests of western United States, these agents recycle far more biomass over the course of natural forest succession than is typically consumed in fires in even the most fire-intensive ecosystems. Epidemics of diseases and insect herbivory have occurred throughout history: Veblen and others (1991) described a series of spruce beetle outbreaks in subalpine forests in Colorado that altered the species composition of forests as far back as 1810. Similar history has been described for western spruce budworm outbreaks in New Mexico (Swetnam and Lynch 1989). Root disease epidemics are common and enduring in large areas of the western United States, particularly in northern Idaho and western Montana (Filip and Goheen 1984, Hagle and Byler 1993, Hagle et al. 1994).

Less intensive activity by pathogens and insects occur on every hectare of forest, every year, and form much of the character of forests (Williams et al. 1992). Both epidemic and endemic types of activities are characteristic of the forests in which most of our native tree species evolved or to which they have adapted (Amman et al. 1977). In this context, it is not appropriate to view pathogen and insect activities as stresses (O'Laughlin et al. 1993): at least not as ecosystem stresses. In fact, they may be important mechanisms by which native biodiversity is maintained.

Pathogen and insect influences on succession are among their most important functions in forests ecosystems. The succession functions of pathogens and insects also may be among the most predictable of the disturbances in forests, particularly when assessed in intervals of decades or more (Amman et al. 1977, Veblen et al. 1991, Goheen and Hansen 1993).

Risk and Hazard Indices Compared to Indices of Successional Effect

Risk or hazard rating systems have been developed for most of the important insects and diseases in western forests (Amman et al. 1977, Hagle et al. 1987, Weatherby and Thier 1992, Ager et al. 1995). These systems have been very useful for predicting where outbreaks are likely to occur and the resulting losses in timber volume. The accuracy of risk and hazard rating systems is a factor of the degree to which the insect or pathogen's behavior is controlled by host and stand conditions. Disease and insect hazard rating has helped establish management priorities in many management plans on western federal lands.

The current emphasis on ecosystem functions provides another opportunity to apply risk and hazard assessments to land management planning. The actions of pathogens and insects can be seen as major influences on the rates and pathways of change in forest cover and structure. When risk and hazard rating systems are applied within the context of succession function, the focus is narrowed to the "risk" or "hazard" of only those actions that result in significant ecological functions.

At the landscape level, tree species, size classes, and canopy structure are commonly used markers for forest succession or successional stages. The remarkable diversity of successional changes or pathways that are seen in western forests are to a large degree attributable to the actions of pathogens and insects. In this analysis we explored the possibility of predicting the types and rates of change based on our knowledge of the probable risk or hazard of insect and pathogen activities associated with successional stages.

Managing for Ecological Outcomes vs. Population or "Damage" Control

Aside from the often substantial loss of merchantable volume, we have placed little emphasis on the roles of pathogens and insects in forests. But timber loss or other direct impacts from tree killing or severe growth reduction are not always the primary focus for management. In such cases, the ecological outcomes of even the most severe outbreaks of insects and pathogens actually may be consistent with management objectives. For example, in some settings, severe root disease killing Douglas-fir, and thereby favoring the ponderosa pine components, may reduce some thinning or weeding expenses associated with managing for "old growth" ponderosa pine forests. In other cases, the open canopy promoted by severe disease may provide habitat otherwise available only shortly after mixed-severity fires. Of course, even where timber productivity is not a primary objective, the long-term low canopy densities that result from root disease may be undesirable. For example, the increased runoff associated with low canopy densities in some watersheds may aggravate streambed destabilization.

Future forest plans will almost certainly be based in part on landscape-level analyses that use successional modeling as their primary prediction tools (Salwasser and Pfister 1994). To assure full consideration of the important succession functions of pathogens and insects in future plans, predictable effects of pathogens and insects must be integrated into developing succession models. Types of successional transition, and time required for transitions to take place, are the primary drivers of the dominant successional models under development in the Northwest (Kurz et al. 1994, Chew 1996).

ANALYSIS OBJECTIVES

The primary objective of this analysis is to identify and characterize important succession functions of forest pathogens and insects in Montana and northern Idaho (USDA-Forest Service Northern Region). These efforts are aimed at 1) describing how pathogens and insects affect spatial and temporal patterns of succession, 2) describing current and historic pathogen and insect regimes (the spatial and temporal patterns of pathogen and insect actions), and 3) predicting future succession trends that reflect the role of pathogens and insects (Hagle 1992, Hagle and Williams 1995).

Pathogens and insects that have broadly significant succession functions in M332a and M333d were analyzed. These are:

- White pine blister rust of western white pine and whitebark pine: *Cronartium ribicola.*
- Root diseases of conifers caused by (primarily): *Armillaria ostoyae, Heterobasidion annosum* (s-type), and *Phellinus sulphurascens.*
- Douglas-fir beetle: *Dendroctonus pseudotsugae.*
- Mountain pine beetle in lodgepole pine, ponderosa pine and western white pine: *Dendroctonus ponderosae.*
- Dwarf mistletoe in Douglas-fir: *Arceuthobium douglasii.*
- Dwarf mistletoe in lodgepole pine: *Arceuthobium americanum.*
- Dwarf mistletoe in western larch: *Arceuthobium laricis.*
- Western spruce budworm: *Choristoneura occidentalis.*
- Stem decay of grand fir, subalpine fir, western hemlock and mountain hemlock, caused by (primarily): *Echinodontium tinctorium.*
- Stem decay of lodgepole pine, western white pine, Engelmann spruce, Douglas-fir, western larch, whitebark pine, ponderosa pine, and western redcedar, caused by (primarily): *Phellinus pini.*
- Stem decay of Douglas-fir, western larch, alpine larch, ponderosa pine, and whitebark pine, caused by (primarily): *Phaeolus schweinitzii* and *Fomitopsis officinalis*; and of western redcedar caused by (primarily): *Poria sericeomollis.*
- Spruce beetle: *Dendroctonus rufipennis.*

For each of these agents the important actions and the functions have been defined. The "actions" on the part of the pathogen or insect, in conjunction with the physical conditions of the polygons, determine the most likely functions of the pathogen or insect. Physical conditions include, the potential vegetation type (habitat type), cover type, structural stage, elevation, and so on. By focusing only on functions which are expected to be significant at this broad scale, many of the actions of pathogens and insects were eliminated from consideration. When applying this analysis system to other ecosections or spatial scales, it may be necessary to add other pathogen or insect functions to the analysis and leave out others to better reflect local conditions or influences.

ANALYSIS STRUCTURE

The analysis consists of four general phases:

1. Measuring 40 years' changes in vegetation

In the first phase, a sample was selected to represent a broad range of forest conditions in each of the ecosections. The forest planning samples selected in the early 1970s was used to minimize the variability in the year the stands were examined. This provided an essentially uniform interval between the 1935-era forest survey, which represented our beginning conditions, and the 1974-1975 stand examinations on the same sites. This was consistent with our objective of examining changes over several decades in a variety of site and cover types while minimizing

the effect of a variable time interval. We then analyzed successional changes from the 1935 era to the 1975 era in polygons covered in surveys from both years. None of the polygons had been burned between 1935 and 1975, so fire influences could not be characterized. Likewise, only a small percentage of polygons had been harvested during this time–too few to characterize harvest-effects–so these were excluded from the study. On the basis of the resulting successional stage changes over the 40-year period examined, transition matrices were produced for each polygon class. These matrices show the probability and outcome of transition for 40 years.

2. **Discovering relationships between pathogen and insect actions and vegetation conditions/geography**

Using the 1975-era stand data, we identified significant pathogen and insect succession functions associated with the polygon classes represented. The types of insect and pathogen actions that lead to significant successional effects, and the conditions under which the actions occurred were examined. From this information, we analyzed the data from 1975-era surveys to assign *Action Probability Index (API)* values (a modified risk or hazard rating system) for each identified action. The polygon classes were then characterized according to their average, range, and frequency distributions of pathogen and insect APIs.

3. **Associating probable actions of pathogens and insects with changes in vegetation**

Pathogen and insect APIs were assigned to polygons based on their 1935-era classes and actual change pathways were assigned causes according to the degree to which pathogen and insect activity apparently influenced that particular type of transition. In some cases, the pathway was assigned the cause "silvical succession," implying that the ecological requirements of the trees were most responsible for the succession trends observed. Pathogens or insects were identified as the cause of transition only for polygon classes with the high action probabilities that also had pathways and rates of change consistent with the outcomes of the pathogen or insect activity.

4. **Translating results to predictions of future trends**

The transition matrix, with pathways, probabilities, and causes, provides a database for development of succession models for the polygon classes included in this analysis. This ability to predict trends is an important part of forest planning efforts. The action probability rating systems developed for each agent and tested against 40 years of actual changes in the sample polygons provides an ecologically-based risk or hazard rating system for each of the major insects and pathogens. From this, not only is the probability of change caused by the insect or pathogen assessed, but the probable ecological outcomes of their actions can be predicted as well. This can be a valuable addition to the risk or hazard rating system that are designed to predict volume losses or outbreak probabilities but not successional outcomes.

ANALYSIS AUTHORS

The analysis was done by plant pathologists and entomologists on the Cooperative Forestry and Forest Health Protection (CFFHP) staff in the Northern Region of the Forest Service, using methods developed in cooperation with specialists and contractors from the Forest Health Technology Enterprise Team (FHTET). Team members and their areas of responsibility are listed below :

James W. Byler, Plant Pathologist, CFFHP, Coeur d'Alene, Idaho. Administrative leader and co-developer of analysis methods for white pine blister rust.

Susan K. Hagle, Plant Pathologist, CFFHP, Kooskia, Idaho. Project technical leader, technology development co-leader, and also provided the analysis of root disease.

Terri L. Johnson, Computer Programmer, CFFHP, Boise, Idaho. Data management.

Sandra J. Kegley, Entomologist, CFFHP, Coeur d'Alene, Idaho. Douglas-fir beetle, mountain pine beetle in western white pine and spruce beetle.

Lowell G. Lewis, Contract GIS and Spatial Analysis Specialist, FHTET, Fort Collins, Colorado. Geographic database development.

I. Blakey Lockman, Plant Pathologist, CFFHP, Missoula, Montana. Stem decays.

Michael A. Marsden, Contract Statistician, Coeur d'Alene, Idaho. Statistical analysis.

H. Ross Pywell, Program Manager, GIS and Spatial Analysis, FHTET, Fort Collins, Colorado. Administrative coordination for technology development.

Carol S. Bell Randall, Entomologist, CFFHP, Coeur d'Alene, Idaho. Mountain pine beetle in lodgepole pine and western and mountain pine beetles in ponderosa pine.

John W. Schwandt, Plant Pathologist, CFFHP, Coeur D'Alene, Idaho. White pine blister rust.

Lawrence E. Stipe, Entomologist, CFFHP, Missoula, Montana. Geographic database.

Nancy J. Sturdevant, Entomologist, CFFHP, Missoula, Montana. Western spruce budworm.

Jane E. Taylor, Plant Pathologist, CFFHP, Missoula, Montana. Dwarf mistletoes.

Stephen B. Williams, Program Manager, Decision Support Systems, FHTET, Fort Collins, Colorado. Technology development co-leader.

SECTION 2: METHODS
Part 1: Data Collection, GIS Processing, and Polygon Classification

THE STUDY AREA

By Michael Marsden and Lowell Lewis

Location

The project area, in the middle and northern Rocky Mountains, falls within the Dry Domain and the Temperate Steppe Regime, Mountains Division (Bailey 1994, Bailey et al. 1994), and is characterized by glaciated mountains, alpine meadows, and coniferous forests. Sections M332a and M333d include the central and southern parts of northern Idaho and western Montana (Figure 2.1).

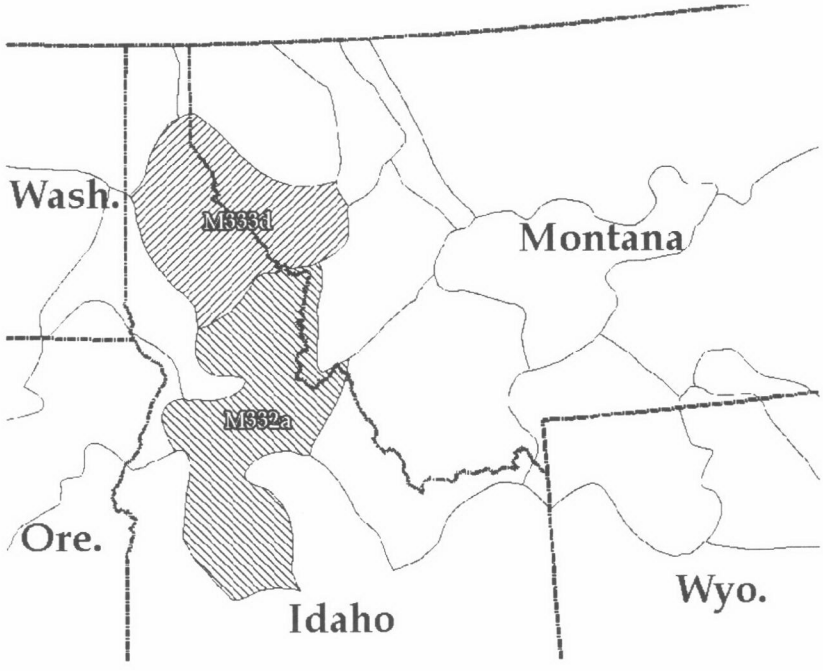


Figure 2.1: Study ecosections in the Northern Rocky Mountains.

Ecosection M332a includes portions of the Nez Perce, Bitterroot, Clearwater and Lolo National Forests; ecosection M333d includes parts of the Clearwater, Lolo, Idaho Panhandle, Kootenai and Flathead National Forests (see Figure 2.2). Ecosection M332a is described by Bailey (1994) as Middle Rocky Mountain Steppe. The geomorphology is glaciated mountains with ridges and cirques, with granite soils (Inceptisols, Alfisols). Potential natural vegetation based on Kuchler's national classification system (1985), is described as grand fir and Douglas-fir, western spruce-fir, and western ponderosa pine forests (Bailey 1994). Ecosection M333d is described as Northern Rocky Mountain Steppe. Geomorphology is described as steep, dissected mountains; lithology is metasedimentary with Inceptisol and Alfisol soils. The potential natural

vegetation includes cedar-hemlock and pine forest. This ecosection includes most of the western white pine forest type to be found in the Northern Rocky Mountains within the United States.

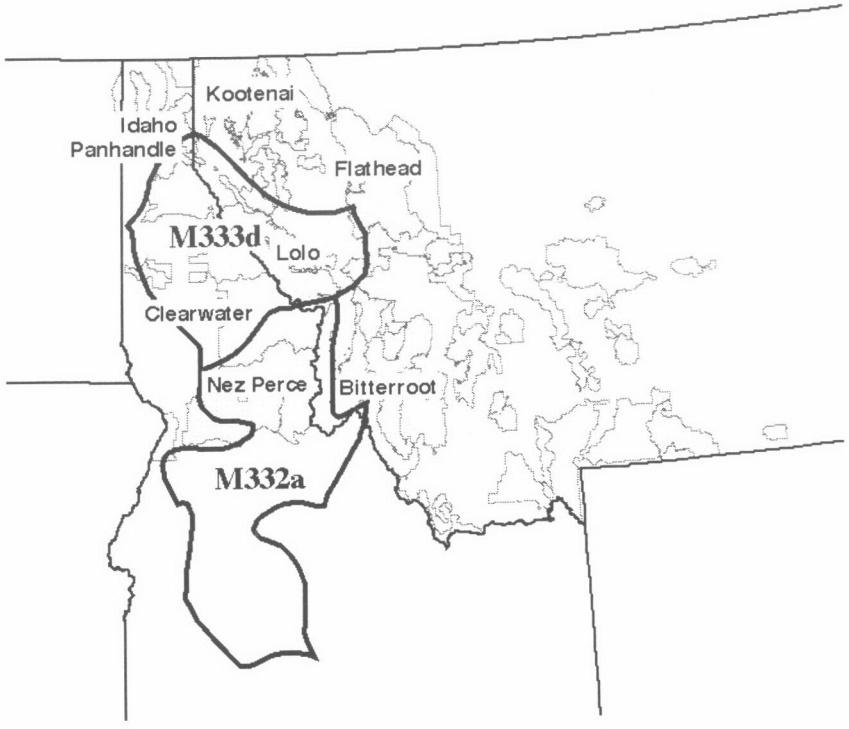


Figure 2.2: National Forests of the Northern Region.

The Project Data

When scientists in the Northern Region considered the long-term effects of forest pathogens and insects in terms of forest succession, they began to formulate a structure in which to model succession and to search for data with which to test their model. The two data sets that were found for the Northern Region covered the area of interest but had very different designs when collected. The first and oldest of these, referred to as the 1935-era data, was a part of a nation-wide survey of forest resources. It included federal, state, and private forest lands, and the statistics were reported by state and county. The second set of data, the 1975-era data, was a cluster-sample survey of the national forests of the Northern Region. With recent advances and availability of technology in Geographic Information Systems, the scientist of the Northern Region saw the opportunity to evaluate the change in forest conditions in the approximately forty years between the two surveys.

The 1935-era data

In 1928, the McSweeney-McNary Forest Research Act authorized the Secretary of Agriculture to make a Nation wide Survey of the forest resources. The administration of the program was given to the various regional forest experiment stations. This field work for the Northern Rocky Mountains began in 1933 and continued until 1943, terminated because of World War II. The field inventory phase had been completed for northeastern Washington,

northern Idaho, western Montana, and four counties in eastern Montana by 1943. This inventory consisted of a complete mapping of the forested area on federal, state and private lands by county. This mapping was based on aerial photographs and field data. Timber volume by species was the prime variable of interest, so the area was mapped by cover types with notations for total volume and species composition. The procedures used are described in a report published in 1948 by the Division of Forest Economics of the Intermountain Forest Experiment Station (USDA-FS 1948). For the forests of northern Idaho and western Montana copies of the maps were relocated or reconstructed from the old photographs.

Western white pine was considered such a valuable species that land was classified as western white pine type if 15 percent or more of the volume was in this tree species. Ponderosa pine held a similar status, with stands containing 25 percent or more ponderosa pine volume being classed as ponderosa pine type. Other cover types are based on the tree species with the largest basal area.

The 1975-era data

In 1970, a new survey of the national forests of the Northern Region was begun. This survey was conducted by the Region with consultation from the Intermountain Forest and Range Experiment Station. The survey design is detailed in An Inventory Design Using Stand Examinations for Planning and Programing Timber Management (Stage and Alley 1972). As in the first survey, timber volume was of prime interest. Forest planning was now to be done in much greater detail, and this inventory was designed to allow stand-level data to be used in the planning process.

The 1975-era inventory procedure, like the 1935-era survey, was based on the photo interpretation of a large number of photo points to stratify the forest area into classes. Whereas in the first survey, these strata were based on timber volume, in the later survey they were defined to emphasize opportunities for timber management. The following statement is taken from Stage and Alley (1972).

> "Our objective for this inventory system emphasize the importance of examining a recognizable stand in relation to the surrounding conditions of the forest lands and their uses. This emphasis is realized by defining the ground sampling unit to be a subcompartment, smallest permanently defined record unit suitable for long-range land management planning, including a comprehensive road system. For the Coeur d'Alene National Forest, a subcompartment encompasses an area of about 1,200 acres, defined by topographic, drainage, and political boundaries. The list of 604 subcompartments and their acreage that make up the Coeur d'Alene National Forest provides a logical sampling framework for not only the timber management planning inventories, but for many other kinds of inventories as well. . . . Within the selected sample subcompartments, stands are mapped from the aerial photographs and examined on the ground using a systematic grid of plots."

In the 1975-era data, there is individual tree data taken on the grid of plots. Using the cover type definitions from 1935 era and the tree data in the 1975-era inventory data, a similar cover type was calculated. Because both methods put stands into rather broad classes, we believe that there is no classification bias between the two data sets.

The subcompartments of the 1975-era inventory were mapped and overlaid on the 1935-era inventory maps to estimate the area by cover type in both time periods. This insures we are examining the same pieces of land for each survey. Then the change or transition is due to changes in the vegetation on a small area of ground but not to changes in the definitions of cover type or a change in the location of the samples.

The 1975 inventory is a random-cluster sample of stands within each national forest in the Northern Region. Unbiased estimates of the conditions on the forests can be estimated from this data. Since each forest was sampled with approximately the same intensity, the summary of the data stratified by Bailey's ecosections should also give unbiased estimates of the conditions of the national forest lands within the ecosection.

There are two exceptions to this in our work so far. Incomplete coverage in aerial photography from the 1930s resulted in part of the Nez Perce National Forest not being covered for ecosection M332a. Ecosections M333a, M333b, and M333c were combined for analysis as M333d.

In general, we are using the summaries of conditions found in the 1975 survey as unbiased estimates of the national forest lands within the Bailey's ecosections. We are also using the changes in the forest conditions from the 1935 inventory data to the 1975 data as first estimates of the probability of change for a given habitat type group, cover type, and structure class. This is likely the best data available to make the estimate of rate of change and probability of change, but the sample was not designed to estimate these changes.

The conditions or factors used in the modeling of the stand succession in the analysis were site class (habitat type groups), forest cover type, and forest structure stage. Each of the ecosection samples were tested to see if the action probability indices (APIs) differed by any these three factors.

It can be argued that the decision was made to model the transitions by structural stage for each cover type within the habitat type groups based on the ecology of the area and the types of management plausible. This is then the structure for modeling forest secession: So why bother to compute any statistical tests? The statistical analyses presented later in this ecosection were computed to test if each of the many APIs differed by factors that were to be a part of the structure to model forest succession. They were tested independently because, although some insect and disease vectors do act jointly on the forest condition, each is capable of making a direct impact on the succession pathway.

The Sample

The samples of sections M332a and M333d consist of most of the subcompartments selected in the early 1970s to supply the first comprehensive forest planning database. There are 698 subcompartments, consisting of 5,686 stands and 72,260 hectares. The subcompartments were drawn as a stratified random sample to represent the range and approximate frequency of conditions in the commercial timber-producing lands managed by the Forest Service (Stage and Alley 1972). Each stand in the sample subcompartments was examined using ground survey and aerial photography sampling methods from 1972 to 1976. Similar methods were used for all surveys, making it a relatively consistent database, compared to the normal variation across national forest boundaries and through time, as survey methods have evolved. As stated earlier, the specific time period was not important to the objectives of this analysis. The sample was judged to represent a broad range of common forest stand conditions and to represent a fairly consistent

point in time across the sample area. This allowed relatively easy comparison with an earlier time period, based on the 1933 to 1937 forest survey of the same locations.

Although only the first two ecosections, M332a and M333d, are reported here, the analysis was undertaken for all of northern Idaho and western Montana. All of the GIS and Oracle database preparation for each of the ecosections within Northern Region boundaries was completed during the data-gathering phase of this project. Reports of findings for the remaining ecosections will be prepared as the analyses are completed.

GEOGRAPHIC DATABASE FOR 1935-ERA AND 1975-ERA SAMPLES

By Lowell Lewis and Lawrence Stipe

Why GIS Was Critical to This Project

There were three dominant reasons for using GIS in this project:

1. **Greater accuracy in registering sample data locations.** To examine with greater accuracy what changes actually take place over time, sampled forest stand data from two distinct time periods had to be linked to the same exact piece of ground for a rigorous comparison of forest conditions. GIS met this need: once the stand boundaries for both datasets had been digitized and co-registered, and the attributes attached to the datasets from both time periods, those attributes could be compared within the GIS by unioning the two spatial datasets together. All attributes from both periods were then accessible by querying any of the 'child' polygons formed from the union of the two sets of 'parent' stand coverages. By accurately maintaining the datasets from both time periods, the GIS supported the validation and calibration of prior Forest Service models and database queries, as well as the creation and validation of new queries specific to this project.
2. **Assignment of attributes.** The earlier of the two datasets (described later) did not carry the habitat type attribute. At the time of that survey, the concept of habitat type had not yet been introduced, whereas habitat type had been assigned to all stands during the later survey. Since habitat type, reflecting predominant conditions in the physical environment, changes very slowly over time, this attribute could reasonably be assigned to stands of the earlier survey from the more recent survey via the same GIS union process. In a similar vein, since the coverage of Bailey's ecosections was registered to the same Universal Transverse Mercator (UTM) projection as all other coverages, it was easy to determine in which section each stand's center was located by applying a 'theme-on-theme' selection and then assigning the appropriate ecocode from the selected stands' attributes table.
3. **Area weighting.** Some of the various combinations of habitat type, cover type, and successional stage had to be summarized for each forest or ecoregion ecosection by normalizing their values over the area of each class. This type of calculation is efficiently and accurately performed by a GIS. Since polygon area is automatically calculated as soon as polygon topology is established, the total number of hectares assigned to each class was easily derived, and that value used in calculating area-weighted statistics.

GIS Methods

The major GIS steps in the processing of this project included acquiring map data from two distinct time periods over the project area, discovering processes by conducting a pilot project, applying those GIS processes through the twelve-forest project area over the two time periods, and making the derived spatial and attribute files available in a usable form for subsequent statistical analyses and comparisons of stand conditions. The following paragraphs describe each of these steps.

Obtaining the maps

Forest maps showing stand-level attribute information for the two time periods were required to determine the successional stage for each stand within the selected subcompartments. Data for this project were collected in the 1930s (hereafter referred to as "1935 era") and in the 1970s (hereafter referred to as "1975 era").

Stand-type maps produced by the Forest Survey group were used to record the 1935-era stand attributes for most of the locations subsequently mapped during the 1975 era. These early maps (Figure 2.3) were hand-drafted township-size (36-square-mile) maps at a scale of 1:31,680 (two inches per mile). Forest type information was color-coded and placed on the original base map, and an alphanumeric coding system was developed to describe the main stand characteristics. This map series was produced for all Forest Service ownership lands in Region 1 except for most areas east of the Continental Divide: thus, the absence of 1935-era data from the Beaverhead, Custer, and Gallatin National Forests (see Table 2.1, below).

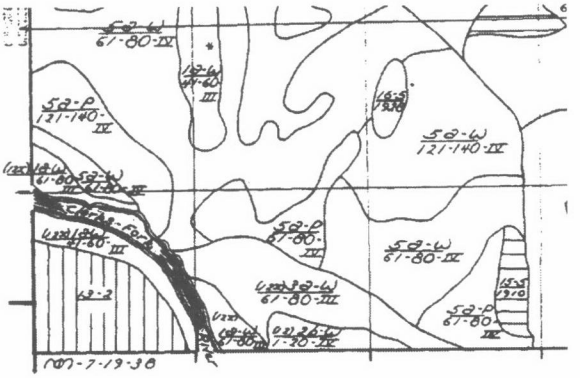


Figure 2.3: Sample 1935-era map.

As is common in most GIS work, data acquisition was an arduous aspect of this project. The only complete set of 1935-era maps was originally stored at the Regional Office Headquarters in Missoula, Montana. Sometime during the late 1960s, however, an employee at the Regional Office decided to dispose of these maps, as outdated. Responding to a tip from a friend on the janitorial crew at the Federal Building, Dale Johnson (Archivist at the University of Montana's Mansfield Library) found the many-volume map set in a dumpster, destined for the local landfill and oblivion. With permission from Regional Office staff, the maps were recovered and are now kept at the University library.

Unfortunately for the pilot project (described below), maps were recovered for all but the Nez Perce and Clearwater National Forests. Data for these areas had to be recreated from aerial photographs taken during the 1930s (stored at the Regional Office) using photointerpretation techniques of the era to produce maps consistent with those recovered. Moreover, because photographs were available for only 7 of the 22 subcompartments of the Nez Perce, the pilot project could be run only on that limited sample.

Collecting the 1975-era base maps at each National Forest headquarters office was another major undertaking. Many individuals involved in this survey had either moved to other offices or were retired, and the important historic value of these maps was not reflected in their

treatment. Many calls and site visits were required to locate the maps. (In fact, maps for the Lewis and Clark National Forest were never found.)

The maps used for the 1975 era were found to have been drawn atop standard 7.5-minute topographic series maps at a scale of 1:24,000. These subcompartment maps (see Figure 2.4, below) usually showed little else but the outer-most boundary and identification number. Mylar map overlays had been used to delineate stand boundaries, habitat types, transect lines, etc. For many maps, line quality and readability were poor: lines and numbers had to be retraced and the overlays rescaled to fit the base map prior to copying the maps and overlays as digitizing source material.

Final stand data available for the study from both time periods is listed in Table 2.1:

Table 2.1: Project forest data available for the study.

Forest	Forest Area (sq. mi.)	Number of 1935-era subcompts.	Number of Stands	Number of 1975-era Subcompts.	Number of Stands
Beaverhead	3,482	0	0	72	548
Bitterroot	2,614	51	313	51	678
Clearwater	2,915	27	138	27	358
Custer	2,030	0	0	36	181
Deerlodge	2,140	35	174	59	598
Flathead	4,093	68	261	68	657
Gallatin	3,391	0	0	60	372
Helena	1,822	26	135	70	462
Idaho Panhandle	4,343	76	450	108	769
Kootenai	4,041	75	298	75	577
Lolo	4,019	60	247	60	665
Nez Perce	3,512	7	62	22	255
Total	**38,402**	**425**	**2,078**	**708**	**6,120**

Establishing a pilot site

A pilot site was chosen in order to discover and perfect techniques prior to processing data from the remaining forests. The Nez Perce National Forest was selected as the pilot forest for the project. Because of limited 1930s photo coverage, the Nez Perce provided the smallest of the twelve forest samples to ultimately be analyzed. However, it promised to be the first National Forest to have both data sets available. Because of the project's time constraints, the Nez Perce was the logical choice.

Digitizing the maps

Assigning stand identifiers. To identify each stand on the hundreds of maps now ready for digitizing, a modification of the nested-hierarchical scheme used in the timber stand database was chosen. In the 1975-era stand-numbering convention, codes for forest, district, compartment, subcompartment, and stand were combined in a unique ten-digit identifier (see the breakdown Table 2.2, below). Not all stand polygons in the 1975-era survey subcompartments had been assigned a stand number; where stands were unlabeled, they were assigned a stand number of 999, and data for stands so-designated were not used in the pilot analysis.

Stands on the 1935-era maps did not contain stand numbers, and so the digitizers assigned an alphabetical character in the final place of an eight-character alphanumeric identifier (see the breakdown in Table 2.2). As a result, all 1935-era and 1975-era stands within the same subcompartment could be related through the same first seven digits in their identifier.

Table 2.2: Stand identifier designations.

	1975-era Stand ID	1935-era Stand ID
Stand identifier format:	(05 1 16 21 012)	(05 1 16 21 E)
Forest code	digits 1 and 2	digits 1 and 2
District code	digit 3	digit 3
Compartment number	digits 4 and 5	digits 4 and 5
Subcompartment number	digits 6 and 7	digits 6 and 7
Stand number	digits 8, 9, and 10	character 8

Digitizing subcompartment boundaries and stand polygons. The first digitizing step was to produce a separate layer, by forest, of the 1975-era survey subcompartment boundaries. The digitizers used additional registration aids, such as Public Land Survey System corners and Digital Line Graphs (DLG) of hydrography, to properly position and register the 1935-era maps. Then, using these 1975-era subcompartment boundaries as a backdrop, they digitized the stand boundaries for both eras up to or just beyond the extent of each subcompartment. Stand boundaries were then clipped (snapped) to the extent of the subcompartment boundaries. This process produced the following three layers:

- 1975-era subcompartment boundary polygons (no internal stand lines),
- 1975-era stand polygons, and
- 1935-era stand polygons.

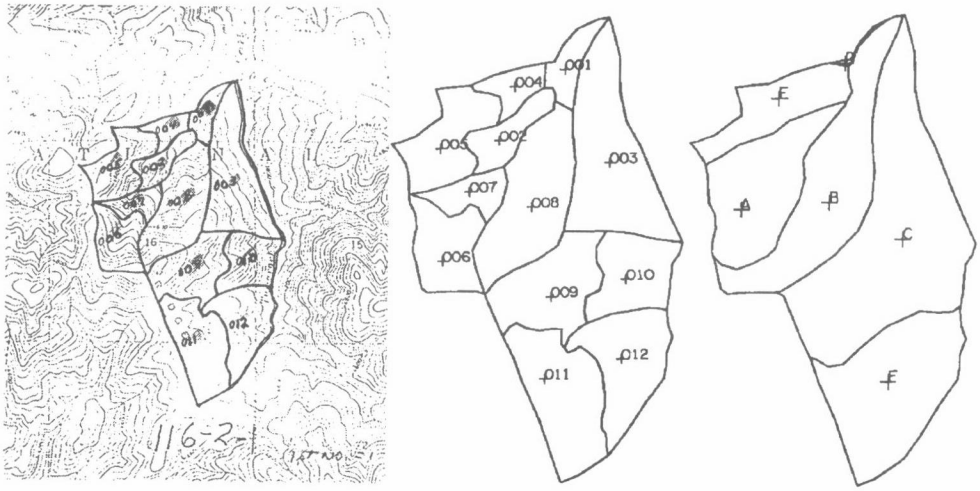
Table 2.3 list the number of polygons created through this process for each of the two time-periods:

Table 2.3: Stand polygons and hectares included in the 1975-era and 1935-era samples, and the proportion of 1935-era hectares covered 1975-era data polygons.

Bailey Ecosection	National Forest	1975-era Sample		1935-era Sample		Proportion
		Poly.	ha.	Poly.	ha.	
M332a	Bitterroot	111	1304	103	1224	0.94
	Clearwater	163	1,874	146	1,452	.77
	Lolo	7	90	7	90	1.00
	Nez Perce	235	3,536	114	1,242	.35
	Total	516	6,804	370	4,309	.63
M333d	Clearwater	288	3,798	288	3,798	1.00
	Idaho Panhandle	891	13,614	872	12,881	.95
	Kootenai	171	1,714	171	1,714	1.00
	Lolo	410	3,706	388	3,671	.99
	Total	**1,760**	**22,832**	**1,719**	**22,065**	**.97**

Establishing the 1935-era attribute database. All attribute data needed for the 1975-era maps were available in the Regional timber stand database in ORACLE format and required no conversion. However, for the 1935-era map set, the stand attribute codes found on the township maps had to be entered by hand as a comma-delimited field in an ASCII data table. All attribute data were entered exactly as found on the hand-drawn map. Any code interpretations and parsing were done subsequently by the analysis staff.

All registration and digitizing tasks were done by Geodata Services, a local contractor from Missoula, Montana, using PAMAP, a non-topological GIS software package. From PAMAP, the spatial subcompartment data were saved in the USGS's DLG Optional-3 file format for importing into ARC/INFO by the analysis staff. The contractor also provided letter-size plots of each subcompartment: one for the 1975-era stands and one for the 1935-era stands (see Figures 2.5 and 2.6 for examples). These copies were used to check for digitizing and data entry errors. 1935-era attribute data associated with the PAMAP polygons were also stored in dBase files, and were later linked to individual stand polygons through common identifier-tags, assigned by the digitizer. Having a digitizing contractor close to both the Regional office and the University library not only made it convenient to transfer both map documents and data files, but it also made quality control (QC) checks much easier.



Figures 2.4, 2.5, and 2.6: Samples of a 1975-era subcompartment map, a 1975-era digitizing check print, and a 1935-era digitizing check print.

Hardware/software selection. At the time that this project was in its planning stages, so was the Forest Service's Project 615, a Forest Service-wide acquisition and implementation of GIS and office automation technologies. By the completion of the technology development project, GIS tools were becoming available throughout the Forest Service for future applications such as this one. It was project staff's early intention to utilize Project 615 components for the TDP: in large part, they succeeded. The key hardware and software components selected in Project 615 for GIS applications (and throughout this project) include IBM RS6000 workstations running ORACLE7, ARC/INFO 7, and ArcView2.

Remaining GIS processing issues

During the design and pilot phase of this project, several key GIS processing issues had to be resolved.

Projection. Seven of the twelve forests analyzed on this project were digitized in UTM Zone 11. For uniformity of display, the remaining five forests were re-projected from Zone 12 to Zone 11. Although the re-projection of Zone 12 forests did cause a slight relative increase in polygon areas (Custer National Forest had the greatest average area increase at 1.0 percent), this did not affect the comparison of attributes and measurement of change over time for identical plots of ground (area being constant for both the 1935-era and 1975-era digitized maps).

Ease of use. ArcView2 was selected as a key software component for this project based on its ease of use by non-GIS professionals, and its ability to easily do 'virtual joins' between ARC/INFO coverages and ORACLE or dBase tables. These tables can be stored in a remote location and edited only by permitted owners. Then, any edits will be automatically reflected the next time that ArcView2 is initialized or re-accesses the table. This assures that current data were always reflected in the analyses.

Data structure. It was originally felt that the raster data structure would be superior to the vector data structure due to its more efficient data storage and more sophisticated analytical capabilities. Furthermore, since cell resolution is selected once during project design, the time-

consuming process of dissolving polygon 'slivers' becomes a moot point with raster analysis. However, when using ArcView2, no raster attributes were available for either viewing or analysis. At the time of this study, ArcView2 treated a raster as a 'dumb' image without attributes, similar in nature to a scanned image. ArcView2 had been deemed an essential component to the accessibility and analysis of the ARC/INFO coverages within this project. Although the ability to analyze raster attributes has been incorporated in subsequent ArcView versions, it was primarily this inability that determined that raster processing be dropped from further consideration at that time.

AML scripts. Due to the nature of this project as a subject for technology transfer, it was determined early on by project staff that Arc Macro Language (AML) scripts would be utilized for the more complicated and redundant ARC/INFO processing steps. Although the actual time savings gained by using the three most sophisticated AML scripts (described later) was not quantified, it was substantial. The advantages become more apparent when considering the potential for exporting this TDP to other regions or ecosystems. These three AMLs were written to be sufficiently flexible that different variable names could be inserted as parameters to the AML command line. In addition, the application of automated procedures established a uniformity of process that could not be duplicated by the manually-implemented methods that were initially employed on trial runs of the first few forests.

Other parameters. During the initial design of this project and the processing of its pilot forest, three key project parameters were established:

1. All stand map polygons which, for any reason, contained no data (non-forested land, rock outcroppings, or water bodies) were deleted and ignored in further analysis.
2. From field surveys, general stand delineation guidelines establish two hectares (five acres) as the minimum stand size. Accordingly, in order to minimize processing time for very small polygons, the project staff selected a minimum polygon resolution of two hectares for stands from both time periods.

   Each post-union polygon of less than 2 hectares in size was treated in one of two ways:

   a. If it had neighbors of the same habitat type group, it was merged into the neighbor with which it shared the longest common boundary arc (see Figure 2.7);

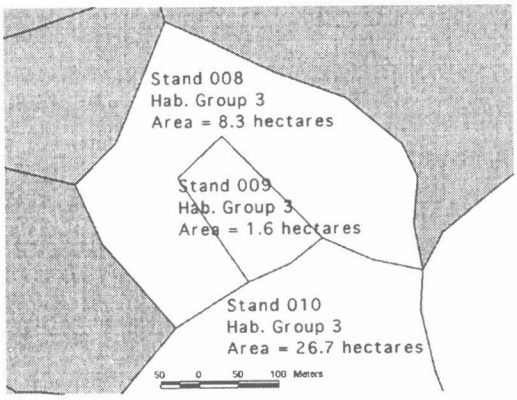


Figure 2.7: Candidate polygons for merging. Small stand 009 would merge into stand 008, with which it shares the longer common boundary arc.

b. If there were no neighbors of the same habitat type group, it was retained. (Groupings of habitat types were used as the distinguishing attribute because the retention of individual habitat types would have resulted in an unmanageable number of classes during the analysis.)

3. Occasionally, separate stands within the same subcompartment had the same stand identifier. A naming convention had to be formulated that acknowledged the identifier duplication, yet allowed the correct piece of ground to be referenced. The solution was to add an additional digit to the duplicated 1935 stand identifier (two stands identified as "1462312A" would become "1462312A1" and "1462312A2") or to index by one the leading numeral of the final three digits of the duplicated 1975 stand identifier (three stands identified as "1462312001" would become "1462312001," "1462312101," and "1462312201").

GIS Processing Sequence

As the spatial and attribute digitizing for each forest was completed in Missoula, the appropriate DLG, dBase, and ASCII data were sent to the Forest Service's Forest Health Technology Enterprise Team (FHTET) offices in Ft. Collins, Colorado, for processing. The shipment was accompanied by previously QC-ed 1935-era and 1975-era check prints of all labeled stands in each subcompartment. All data was loaded into forest-specific ARC/INFO workspaces on FHTET's IBM RS6000 workstation. The DLG files were imported as ARC/INFO vector coverages, cleaned, and dangling nodes removed. All polygons were checked for labeling and node errors, and visually verified against the check prints supplied by the digitizers, where necessary.

The ORACLE data, including 1975-era successional stage attributes, were also transferred to Ft. Collins by the Missoula FHP staff and made available to ARC/INFO. (In future applications of similar projects, it is anticipated that all ORACLE stand data will be stored on RS6000 workstations at each forest, and will be made available to multiple locations simultaneously via a Forest Service-wide network.)

Following the importing, editing, cleaning, and re-projection of the forests' coverages in ARC/INFO, the general ORACLE, ARC/INFO, and ArcView2 processes used for a typical forest were:

1. The 1935-era attributes that were delivered in comma-delimited format by the digitizers were imported into ORACLE tables.
2. The stand tables from both eras were joined to the 1935-era and 1975-era polygons using SQL*Net (the required ORACLE networking library) in ArcView2 via the matching records in the unique identifier-tag field within both the coverage and the appropriate attribute file.
3. The 1975-era ORACLE attribute table was also exported as an INFO file for subsequent use in identifying stands that contained no data (following step).
4. The 1935-era and 1975-era coverages were unioned in ARC/INFO, and the first two AMLs were run. These AMLs compared each post-union polygon to its related INFO file, identified those polygons which had no 1975-era data, flagged them, and dissolved them into ARC/INFO's 'universe polygon', in effect deleting them, so that they were ignored in further analysis.
5. The third AML was then run on the output of the second AML to find any remaining unioned polygon that was smaller than 2 hectares (a 'sliver') and merge it with the neighbor of the same habitat type group with which it shared the longest common boundary arc, if such a neighbor existed.
6. The output coverage from the three AMLs (consisting of all unioned polygons that met all prior criteria for existence) was added to ArcView2 as the final 'theme', and was joined to both the 1935-era and 1975-era attributes.
7. An export ASCII file containing key attributes was created in ArcView2 and combined with other attributes within ORACLE, and a query was run to derive the 1935-era successional stage of each polygon.
8. The table of successional stages and other essential derived attributes was made available to ArcView2 and was joined to all unioned coverage polygons. Tables were prepared within ORACLE and transmitted to other project staff for final statistical analysis and derivation of the transitional matrix.

SITE AND VEGETATION CLASSIFICATION

By Susan Hagle and Terri Johnson

Site Classes

Habitat types were assigned to polygons during ground surveys using typing systems current in 1975-era (Daubenmire and Daubenmire 1968, Pfister et al. 1977). Polygons were then classed into habitat type (HT) groups according to a procedures recently developed by a team of specialists for the National Forests of northern Idaho and western Montana (Applegate et al. 1995). This system groups habitat types into classes ranging from hot, dry habitat types to cold, wet types (Table 2.4).

Table 2.4: Habitat type groups used in this analysis based on Applegate et al. (1995).

HT Group #	Description	Codes for Habitat Types (USDA 1992)
1	warm, dry	130, 140-142, 160-162, 210, 220, 230, 311, 321
2	moderately warm, dry	170-171, 190, 250-263, 280-283, 292, 310, 313, 320, 322-324, 330, 340, 350, 360, 370, 505-508
3	moderately warm, moderately dry	290, 291, 293, 510-512, 515, 590-592, 523
4	moderately warm, moist	516-522, 542-526, 529
5	moderately cool, moist	530-535, 545-548, 555, 565, 570-578
6	moderately cool, wet	540-542, 550, 560
7	cool, moist	420-422, 470, 579, 620-625, 660-662, 670-674, 680-682, 685-687, 733, 832
8	cool, wet	410, 440, 480, 610, 630-632, 635-637, 650-655, 675-677
9	cool and moderately dry	450, 640, 641, 663, 690-694, 710-713, 720, 731, 750, 780, 910, 920, 930, 950
10	cold, moderately dry	730, 732, 740, 820, 830, 831, 840-842, 925, 940
11	cold	850, 860, 870
15	grassland steppe	015

Vegetation Classes

We used two distinct forest cover type classification systems, one was consistent with the 1935-era forest survey and the second was refinement of the SILC (Redmond and Prather 1996) cover type classification, which allows for greater discernment of tree species composition in mixed forest types. , We refer to the 1935-era system as cover type. We refer to the modified SILC system as forest type.

Cover type classification

Cover types as defined in the 1935-era forest survey were broad classes designed to identify sources of preferred timber species (see Table 2.5). These types had been assigned to the polygons on the 1935-era survey maps. Based on the rules applied during the 1935-era survey, we classed the 1975-era polygons using the 1975-era survey type 20, stand examination data.

Table 2.5: Assigning 1935-era cover type to 1975-era polygons using R1-Edit stand summary tables.

The Oracle script followed a stepwise procedure in which a polygon was assigned the first cover type for which it met the criteria. The steps are as follows:

Description	Cover Type Code	Total TPA	and/or	Total BFV
Nonforest	19	<25	and	<4000

If the stand had GE 25 total TPA or GE 4000 total BFV, then follow the next set of criteria:

Description	Cover Type Code	Species Code	% Cubic ft. Volume	and/or	Live species or HT
White pine	1	WP	GE 15		
Ponderosa pine	2.8	PP	GE 80		
Ponderosa pine mixture	2	PP	GE 25		
Larch/Douglas-fir mixture	3	L or DF L	GE 75 GE 10	and	
Western hemlock/grand fir mix	4	WH or GF	GE 50	and	GE 1 WH or 502, 565, 570-579
Douglas-fir	5	DF	GE 60		
Engelmann spruce	6	S	GE 50		
Lodgepole pine	7	LP	GE 50		
W. redcedar	8	C	GE 50		
W. redcedar/ grand fir mix	9	C or GF	GE 50	and	GE 1 C and 501, 530-560

Subalpine	11	AF, MH, WBP or AL			GE 1 live tree
Grand fir 1	9.1	GF	GE 50	and	GE 1 GF and 501, 530-560
Grand fir 2	9.2	GF	< 50	and	GE 1 GF and 501, 530-560
Douglas-fir 2	5.2	DF	< 50		
Engelmann spruce 2	6.2	ES	<50		

Forest type classification

The classes are similar to SILC classes with the exception of multiple species cover types (see Table 2.6). The single- and two-species cover type rules are the same for both SILC and the system used in this analysis. The three-species codes replace the general cover types used in SILC, such as mixed mesic forest. Therefore, the classes used in this analysis can be collapsed into SILC classes, if desired. Percent basal area by species was the basis for determining the percent coverage for each tree species for stands averaging 5 inches in diameter at breast height (DBH) or greater. For those stands averaging less than 5 inches DBH, the percent canopy cover (PCC) by species was used from R1-Edit tables.

Table 2.6: Assigning forest type to polygons based on percent canopy cover (for stands averaging less than 5 inches DBH) or percent basal area (for stands averaging 5 inches or greater DBH).

Stepwise Progression to Assign Forest Type	
Single-species forest types:	66 percent or greater canopy cover by a single tree species. The forest type was designated using the two (or one) character species code (e.g., DF or C).
Two-species forest types:	80 percent or greater canopy cover by any two tree species combined. The forest type was designated using the species codes of both species (e.g., DFGF or DFC).
Three-species forest types:	The three tree species that have the greatest canopy cover. The forest type was designated using the species codes of all three species (e.g., DFGFC or DFLC).

To retain a workable classification system (avoid having too many classes for analysis), the combinations were made in alphabetical order, so that the two-species combination of Douglas-fir and grand fir was always be designated DFGF, and a three-species combination with Douglas-fir, western larch and western redcedar was C DFL.

Structure classification

Structure classes were based on the combination of the size and density of trees on the site. The 1935-era survey data contained information about the cover type, size class, stocking density, age class, and, generally, the percent composition of stands by tree species. To facilitate

more direct comparison of the 1935-era data and the 1975-era data in each polygon, a structure classification system was devised to use the available data from the 1935-era maps. To apply the five-structure classification system to the polygons combinations of size class, stocking class, and, in some cases, age class were used. Table 2.9 illustrates the logic of the Oracle script, LA_HIST_SC, which applies the structure class to polygons from 1935-era data.

Applying these same structure classes to the polygons using 1975-era data necessitated assigning cover (Table 2.5), size (Table 2.7), density (Table 2.8), and age classes (Table 2.9) to the polygons representing the 1975-era time period. Tables 2.5, 2.7, and 2.8 contain details of the Oracle scripts that were developed to accomplish this classification of the polygons from 1975-era data. The script, called CURR_COVER_TYPE_1935, runs successively to assign the cover type, then size class and, finally the density class. Age classes were available directly in the stand summary tables from the R1-Edit database. Once the cover type, size and density classes were assigned, an Oracle script, called LA_STR_STG, was run to assign the structure class (Table 2.9) to each polygon for the 1975 era.

Table 2.7: Assigning the size class code to stands based on cover type, stand volume, and size criteria.

Cover Type Codes	Total BFV/acre	% CFV Sawlogs*	Total TPA GE 6" DBH	Total TPA Cedar GE 10" DBH	Size Class Code
1, 3, 4, 5, 5.2, 6, 6.2, 9.1, 9.2	GE 4000	GE 50			S (sawlog)
	<4000	< 50	GE 25		A (pole)
	<4000	< 50	< 25		B (seedling/sapling)
2, 2.8, 7, 11	GE 3000	GE 50			S
	<3000	<50	GE 25		A
	<3000	<50	<25		B
8, 9	GE 4000	GE 50			S
	<4000	<50		GE 8	A
	<4000	<50	GE 25	<8	B
	<4000	<50	<25	<8	C

* Sawlog designation criteria are: GE 12 inches DBH for western white pine, ponderosa pine and western redcedar; GE 14 inches DBH for all other species. The percent (%) cubic foot volume (CFV) per acre is obtained by adding up the CFV/acre of all sawlogs and dividing by the total stand CFV.

Table 2.8: Boardfoot volume per acre requirements used to code the stocking density of stands.

Cover Type Codes	Size Class Code	Total BFV/acre	Total TPA	Stocking Code
2, 2.8, 7, 11	S	GE 3000, < 7000		P (poor)
		GE 7000, <13,000		M (moderate)
		GE 13,000		W (well)
All other forested	S	GE 4000, <10,000		P
		GE 10,000, <20,000		M
		GE 20,000		W
All forested	A, B or C		GE 25, <79	P
			GE 79, <200	M
			GE 200	W

Table 2.9: Assigning structure classes to polygons using 1935-era or 1975-era data.

Cover Type Code	Size Class Code	Stocking Code	Age Class	Structure Class Code
8 or 9	S or A	W		3
		M or P		4
	B	W or M		2
		P	GE 0, <60	2
			GE 60	4
	C	W, M or P		1
All others	S	W		3
		M or P		4
	A	W or M		2
		P	GE 0, <60	2
			GE 60	4
	B	W, M or P		1

Polygon data representing the 1935 era and the 1975 era are stored in Oracles tables called LA_STARTING_STANDS and LA_ENDING_STANDS. The polygons in both tables are those resulting from the union of ARC coverages of 1935-era maps and 1975-era polygons. Where 1935-era survey maps were lacking, the polygons used are the 1975-era polygons. Where 1935-era data were available, they were nearly always available for the entire sample sub-compartment.

Assigning cover and structure function codes

The changes or "transitions" in cover and structure were assessed for each of the polygons which were examined in both the 1935-era survey and the 1975-era resurvey. The transitions were summarized for each beginning class according to the proportion of hectares in each ending class (Table 2.10).

Table 2.10: A sample of transitions observed in M333d from the 1935 era to 1975-era resurveys of polygons beginning with a larch-Douglas-fir cover type and moderately- to well-stocked pole size structure class.

Beginning Class (1935)			Ending Class (1975)		Proportion Of Hectares
HT Group	Cover Type	Structure Class	Cover Type*	Structure Class*	
5	3	2	9	2	0.32
5	3	2	4	4	.11
5	3	2	9	4	.11
5	3	2	1	2	.10
5	3	2	8	2	.08
5	3	2	4	2	.06
5	3	2	5	2	.05
5	3	2	4	3	.05
5	3	2	7	2	.03

*See Table 2.5 for interpretation of cover type codes, and Table 2.9 for structure class codes.

The changes in cover type or forest type and structure were observed to fall into several categories, which were used to identify the general types of influences the pathogens and insects were thought to have on each pathway. For example, a change from an early seral species composition as indicated in cover type codes 1, 2, 2.8, 3, or 7 to a mid- to late-seral species composition such as 4, 5, 8, 9, or 11 was interpreted to represent a cover change described as increase in climax composition (Table 2.11). Similarly a change in forest type from DFPP to DF or DFGF was designated as increase in climax composition. A change from DFPP to DFWL was designated maintain early seral, as was DFPP remaining DFPP on all but habitat type group 1 where ponderosa pine is expected to be climax on some habitat types. In habitat type group 1, DFPP remaining DFPP was considered to have a stable species composition.

Table 2.11: Cover function codes based on type of cover change observed in pathogen or insect- influenced successional pathways.

Cover Type Change Categories	Code	Transition Types
Increase climax species composition	CC	Early-seral to mid- or late-seral, Mid-seral to late-seral
Species composition stable (no change expected)	MM	Mid-seral remaining mid-seral, Late-seral remaining late-seral
Maintain early seral component/s	MS	Early-seral retaining early-seral (not necessarily the same species)
Increase proportion of early seral components	IS	Mid-seral or late-seral changing to early-seral

Structure class changes were assigned codes based on beginning and ending structure classes. Table 2.12 details the methods used to determine the structure change designations for each pathway. The interpretation of changes in structure varies somewhat according to expected mature tree sizes and density for the habitat type group.

Table 2.12: Category of structure change assigned to pathways according to the structure transition type in the pathway.

HT Groups 1-6, Non-LP Cover on HT Group 7	Code	Transition Type
Structure stable (no change expected)	MM	SC 3-> SC 3
Canopy closure prevented (low canopy density results)	PC	SC 0, 1 or 2 -> SC 4
Normal change to larger trees with nearly closed canopies	NN	SC 0 -> SC 2 SC 0, 1 or 2 -> SC 3
Largest trees die; move toward young, small tree classes	ES	SC 3 or 4 -> SC 0, 1 or 2
Structure stalled in young, small tree class	ST	SC 0 -> SC 0, SC 0-> SC 1 SC 1 -> SC 1, SC 2 -> SC 2, SC 1 -> SC 2, SC 2 -> SC 1 or 0
Large-tree structure; decrease in canopy density	DD	SC 3 -> SC 4
Large-tree structure; increase in canopy density	ID	SC 4 -> SC 3

HT Groups 8-15, and LP Cover Types on HT Group 7	Code	Transition Type
Structure stable (no change expected)	MM	SC 2 -> SC 2, SC 3-> SC 3
Canopy closure prevented (low canopy density results)	PC	not considered
Normal change to larger trees with nearly closed canopies	NN	SC 0 -> SC 1 or 2 SC 0, 1 or 2 -> SC 3
Largest trees die; move toward young, small tree classes	ES	SC 3 or 4 -> SC 0, 1 or 2
Structure stalled in young, small tree class	ST	SC 0 -> SC 0, SC 1 -> SC 1
Large-tree structure; decrease in canopy density	DD	SC 3 -> SC 4
Large-tree structure; increase in canopy density	ID	SC 4 -> SC 3

The cover and structure changes are coded in the database as a two-letter code assigned to each pathway in tables representing the observed transitions by polygon classes using habitat type group/cover type/structure class and habitat type group/forest type/structure class.

Comparisons of starting and ending vegetation classes using forest type classifications

An additional transition model was calculated based on probable forest types in the 1935 era and actual forest types in the 1975 era. This model is useful in approximating changes in forest type as well as structure classes over a 40-year period in the absence of tree harvest activity. The basis for calculating the probable forest types in the 1935 era was the relationship between cover type classes and forest type classes assigned to the 1975-era samples within a habitat type group and structure class. Within each habitat type/cover type/structure class polygon class there was a finite set of forest types assigned. The relative frequency of each forest type was used to calculate the probability of each Type in the 1935-era sample.

It is likely that certain species in the cover types would be more abundant in the 1975 era than they were in the 1935 era. For example, a ponderosa pine/Douglas-fir mixed cover type in the 1975 era probably had relatively more Douglas-fir than did the same cover type in the 1935 era. Similarly, a lodgepole pine cover type probably had more subalpine fir in the 1975 era than most of that type would have in the 1935 era. These inaccuracies aside, the general composition represented by a cover type at a particular structure class within a particular habitat type group are probably comparable between 1935 and 1975 eras.

We assessed a variety of strategies for assigning a forest type to the 1935-era polygons, and settled on a approach that apportioned the hectares within a habitat type group/cover type/structure stage class based on the proportion from the 1975-era polygon classes, but minimized artificial changes in forest type. Thus the hectares in cover type 5 in M332a were considered to be 65 percent DF, 32 percent DFGF, and 3 percent DFWH forest types unless the ending forest type was DF, DFGF or DFWH. If the ending forest type (the 1975-era type) of a polygon was among the forest types that corresponded to the cover type assigned in the 1935 era, this forest type was assumed to have been present in the polygon in the 1935 era as well. This conservative method may have resulted in less apparent change in forest type than actually occurred, but avoided calculating an artificially high rate of change in the model.

In most cases, the succession functions of pathogens and insects were assessed based on transitions in cover type. In cases in which forest type transitions were also examined (e.g., mountain pine beetle in lodgepole pine and ponderosa pine, Douglas-fir beetle, dwarf mistletoes and stem decays), they were found to be very similar, and consistent with those observed using transitions based on cover types. Since cover types (as used in the 1935-era survey) are not commonly assigned to forest polygons currently, models of succession based on forest type are likely to be more useful in the near future.

SECTION 3: METHODS
Part 2: Indices for Pathogen and Insect Action Probabilities and Succession Influence

The Action Probability Index (API) is an index to the relative probability that a pathogen or insect will be present in a stand AND will be active in ways which result in successional effects. For example, consider the actions of needlecast fungi compare to those of root pathogens: needlecast fungi are commonly active in stands, killing some part of the foliage, but these actions are unlikely to result in successional effects; in other words, the needlecasts may be active in a stand but they generally will not function in succession. The primary action of root pathogens is directly killing Douglas-fir (*Pseudotsuga menziesii*) and true firs (*Abies* sp.) of all ages; a number of successional effects can be expected including pushing the species composition toward climax species and stalling succession in a successionally early cover and structure class. The distinction between an action and a function allows us to narrow the focus of this analysis to only those actions that have a corresponding successional function.

In some cases, a pathogen or insect may have more than one, distinct, pattern of action in stands that can be related to different successional functions. An example of this is seen in Douglas-fir beetle (*Dendroctonus pseudotsugae*): the beetle has a "weeding" action in which single Douglas-fir trees or small groups are killed; they also have a "outbreak" action in which large parts of a polygon or multiple polygons can be greatly altered in composition by the death of mature Douglas-fir trees. The two types of action on the part of Douglas-fir beetle are likely to have very different successional functions. The queries designed to detect the conditions under which the two types of Douglas-fir beetle actions may occur are distinct and independent.

WHITE PINE BLISTER RUST: ASSIGNING APIs

By John Schwandt and James Byler

White pine blister rust requires both a white pine host and an alternate host in the genus *Ribes*. On sites capable of supporting both hosts, it is reasonable to expect some amount of infection to occur. The level of infection among stands with both hosts present varies considerably. This is mostly due to site conditions that influence the ability of the fungus to establish infections and grow. In this analysis, we examined the influence of both the site hazard (independent of the presence of the pine host) and the current rust API as the combined influence of the site conditions and the current status of white pines in the stand. Both the hazard and current API indices were assigned to each polygon in the samples.

White Pine Blister Rust Hazard

Stillinger (1943) defined rust hazard as the favorableness of the particular site for the development of the rust. The potential for white pine blister rust to infect white pines depends in large part on site attributes that are favorable for the fungus. In particular, the timing and abundance of moisture in the air, either as rain or fog, will influence the ability of the fungus to sporulate, spread, and infect both the white pine and the *Ribes* hosts, and temperature will influence the growth of the fungus and viability of spores. Local weather patterns, aspect, and elevation are each important contributors to site temperature and moisture. The site habitat type is closely related to these site attributes, and is more readily available than the individual rainfall,

humidity, and temperature measurements. For the purpose of this analysis, we were interested in broad classes of site hazard, so we used groupings of habitat types to produce just five classes (Table 3.1). The habitat type groupings were based on a single potential climax species in each habitat type.

Table 3.1: White pine blister rust hazard assignment based on habitat types.

Climax Tree Species of the Habitat Type	Habitat Type Group(s)	White Pine Blister Rust Hazard
Ponderosa pine or Douglas-fir	1	0
Whitebark pine	9, 10, 11	2
Subalpine fir	7, 8	1
Grand fir	3, 4	3
Western redcedar, western hemlock	5, 6	4

White Pine Blister Rust Current API

In addition to site hazard, we looked at the current potential for blister rust effects in stands based on the abundance and size of western white pine and whitebark pines present in the stands. Table 3.2 summarizes the results of the white pine blister rust Oracle script that assigned these APIs. The script is based on habitat type group and the characteristics of the white pine component in a stands: its average diameter, and percent of trees per acre or basal area.

Table 3.2: Blister rust APIs based on current stand and site conditions.

WP Component		Northern Idaho and Montana Habitat Type Group			
Avg. DBH	%TPA or BA	C/H* 5,6	GF 3,4	SAF 7,8	WBP 9,10,11
0-4.9"	<15%	1	1	1	1
	15-49	8	7	6	8
	>50	9	8	7	9
5-11.9"	<15%	1	1	1	1
	15-49	6	5	5	6
	>50	7	6	5	7
>12"	<15	1	1	1	1
	15-50	5	5	4	5
	>50	6	5	5	6

Low numbers indicate relatively little probable effect.

* C/H = western redcedar or western hemlock potential climax species,
GF = grand fir potential climax species,
SAF = subalpine fir potential climax species, not including those which are listed as supporting whitebark pine as a major seral species,
WBP= habitat types that support white bark pine as a climax or major seral species.

The biological basis for these ratings is that stands of small trees tend to be affected more quickly, often losing most of the white pine components in one or two decades because small trees are more rapidly girdled. The combination of small-diameter trees and high proportions of white pine yields stands which are highly vulnerable to blister rust damage (Hagle et al. 1989). Therefore, the highest index numbers are in stands with a high proportion of white pine with a low average white pine diameter. The values also incorporate observations from preliminary data analysis that showed transitions occurring that were probably due to blister rust. Successional transitions occurring in white pine forest types with large diameter white pines indicated that both mountain pine beetle and blister rust probably played important roles.

Mortality due to blister rust is generally greatest on the wettest habitat types with moderate temperatures, primarily because of a more favorable environment for infection and growth (Moss and Wellner 1953). Therefore, cedar and hemlock habitat types (groups 5 and 6) have slightly higher blister rust APIs than grand fir habitat types (3 and 4), which, themselves have slightly higher API values than the subalpine fir habitat types (7 and 8). The higher ratings for the whitebark pine habitat types is due to the relatively greater susceptibility of whitebark pine to infection by white pine blister rust (Hoff et al. 1980).

ROOT DISEASE APIs: RATING FOR ROOT DISEASE SEVERITY

By Susan Hagle

Root disease effects are uniquely visible at stand levels or greater as temporally continuous features of sites. That is to say, if it's here today, it won't be gone tomorrow. Root disease effects are evidenced in the forest structure and density, and in the uneven distributions of mortality among tree species.

Root disease in polygons was evaluated in this analysis using aerial photography. The photographs were interpreted to assign a severity index value on a scale of 0-9 to reflect the relative degree of effect observable in the polygon. A rating of "0" implies no visible effect from root diseases and "9" indicates root diseases have so severely affected the polygon that there are no remaining live overstory trees. All other values are relative to these minimum and maximum effects. Color aerial photographs at 1:24,500 were interpreted stereoscopically using the methods described in Hagle (1992).

In all cases, the severity rating is applied on the basis of the amount of CHANGE FROM NORMAL on the plot that is ATTRIBUTABLE TO ROOT DISEASE EFFECTS. A general familiarity with the local conditions is important for application of this rating system. A clear distinction is drawn between the overstory trees of a non-root disease-tolerant species (referred to as the susceptible species) and the understory that is a result of disease-caused openings in the canopy. Uneven-aged structure resulting from other causes is considered normal (with respect to root disease); the disease severity is based only on the changes from normal caused by root disease. This, of course, may include a considerable amount of bark beetle activity inasmuch as the beetles have the habit of cohabitating with root disease.

These are subjective rating systems: communication tools. The scale is intended to reflect relative impacts useful for management decisions. The lack of clear distinction between adjacent classes reflects the fact that disease severity does not, in reality, jump from class to class. Two users need not be concerned if they rate the polygon or plot differently by a class. A difference of more than one class indicates that the two users need to compare thoughts on the rating.

Cutting history, age, species composition, and physical features of the site must be taken into account when applying these rating systems. A user should visualize the extremes of the scale: no root disease versus no surviving overstory, for each polygon or plot, and then "estimate" the position of the polygon or plot between the extremes. Where, for example, thin or dry soils limit stocking density, the 'no root disease' end of the scale will have considerably less canopy than sites with higher site potential.

Severity Rating Using Aerial Photographs

Whether the polygons are vegetation stands or drawn as root disease severity classes, photointerpretation is surely among the most rapid techniques for assessing current levels of root disease activity on sites. Even so, severity rating approximately 25,000 acres using 1:12,000 to 1:24,000 true color photography, with minimum polygon size of approximately 20 acres, can be expected to take one person about 2 days. The scale of delineation (minimum polygon size) should correspond to the scale of analysis needed. This, in turn, will dictate the scale needed in the photography. Williams (1973) used 1:4000 color infrared aerial photography to identify individual root disease patches.

Stereoscopic pairs of vertical true-color or color-infrared aerial photographs of 1:15,840 or larger scale are recommended. Magnification using a 10X lens mounted on the stereoscope was useful for careful examination of some trees and suspected downfall. When using 1:15,840 or similar scale, some stand data is useful to be sure that species identifications are generally correct. Croft et al. (1982) have provided some nice guidance on identifying species.

Familiarity with the general conditions in the area is essential for good interpretation of the symptoms seen in the photography. Stand examination information for a sample of polygons in each area interpreted can provide, not only a general sense of species composition and structure, but some idea of the types of insect and pathogen activity found in the area. Conversely, the photography often provides a very useful perspective that is not easily obtained by walking through a stand on the ground. Canopy closure or area occupied by root disease patches are the basic characteristics used to assign severity in photo-rating polygons (Table 3.3).

Table 3.3: Rating root disease severity using aerial photography.

Root Disease Severity Code	Description
0	No evidence of root disease visible in the polygon.
1	Root disease present in small, scattered patches of mortality or few, scattered dead trees. Barely distinguishable in the photo.
2	Root disease present in small, scattered patches, infrequent individual dead trees or few larger patches, constituting less than 10 percent of polygon area.
3	Root disease patches sufficient to serve as distinguishing characteristic for polygon delineation, or 10-20 percent canopy reduction by scattered mortality.
4	Small and/or large root disease patches obvious, resulting in 20 30 percent overall canopy reduction, or 20-30 percent of polygon area in non stocked patches.
5	Small and/or large root disease patches obvious, resulting in 30-50 percent overall canopy reduction, or 30-50 percent of polygon area in non-stocked patches.
6	Small and/or large root disease patches resulting in 50-75 percent overall canopy reduction, or 50-75 percent of polygon area in patches that have few remaining overstory trees, of an non-root disease-tolerant species, consistent in age with the non-root disease stand origin.
7	At least 75 percent of the polygon area in root disease patches that have few remaining overstory trees, of a non-root disease-tolerant species, consistent in age with the non-root disease stand origin, or scattered mortality which has resulted in at least 75 percent reduction in canopy.
8	All of the polygon area occupied by root disease patches with a few remaining overstory trees, of a non-root disease-tolerant species left consistent in age with a non-root disease stand origin.
9	All of the polygon area occupied by root disease patches with no remaining overstory trees, of a non-root disease-tolerant species left consistent in age with a non-root disease stand origin.

Root Disease Influence on Succession: Assigning Succession Influence Index Values

The relative influence of root disease in a successional pathway was indicated by the combination of root disease severity values and the likelihood that a particular pathway is consistent with the effects of root disease. The root disease severity statistics for each polygon class represented in the 1935-era polygons were examined initially for the proportion of hectares rated as '0', indicating that there was no root disease influence. The transitions that indicated the least influence from root disease would be expected to be associated with the proportion of hectares with no, or little, root disease.

For example in M333d, habitat type (HT) group 4/forest type (FT) DFGF/structure class (SC) 4, there were two dominant transitions observed. One of the transitions was toward increased density, with the overall stand size class remaining large, and the addition of western hemlock to the forest type (DFGFWH). This is a likely consequence of 40 years of ingrowth of western hemlock in the stands. There were no polygons in the 1975-era sample that were rated as '0' for root disease severity, but nearly half (38 percent) of them were assigned fairly low values of 1 or 2. The remaining polygons had been assigned moderate to high severity values of 3, 4, 5, and 6. The overall average root disease severity for the polygon class was 3.54. The only other transition observed from the 1935-era polygon class DFGF/SC 4 was to DFGFLP/SC 4. Canopy closure had not occurred, or had been lost over the interval, and lodgepole pine which was probably present in relatively small proportion in 1935 had been elevated to significant enough presence to be counted included in the forest type by 1975. This type of transition is consistent with moderate to high levels of root disease activity. The resulting transition matrix for this polygon class is as follows in Table 3.4.

Table 3.4: Influence of root disease on transitions from 1935-era class HT 4/FT DFGF/SC 2.

1935-era Class	1935-era Avg. RRSV	1975-era Class	Proportion	Root disease Influence Index
HT 4/FT DFGF/SC 4	3.54	FT DFGFWH/SC 4	42%	Low
		FT DFGFLP/SC 4	58%	High

Many polygon classes had several types of transitions, but the method used to assign the succession influence index value was the same. Also, in HT group 4 and 1935-era forest type DFGF, but starting structure class 4, there were four transition types observed, two of which would have been highly influenced by root disease. The Table 3.5 illustrates the transitions from this polygon class over the 40-year interval:

Table 3.5: Transitions from the 1935-era class HT 4/FT DFGF/SC 4.

1935-era Class	1935 Avg. RRSV	1975-era Class	Proportion
HT 4/FT DFGF/SC 4	2.51	FT DFGF/SC 3	21%
		FT DFGF/SC 4	59%
		FT GF/SC 1	08%
		FT GF/SC 4	12%

In this class, like the previous polygon class, there were no polygons rated as '0' for root disease severity. The root disease severity frequencies for the class were as in the following table (Table 3.6).

Table 3.6: The proportion of hectares in class HT 4/FT DFGF/SC 4 by root disease severity class.

RRSV Class	Proportion
1	12%
2	11%
3	18%
4	22%
5	19%
6	15%
7	6%

The 23 percent of hectares assigned severity levels 1 and 2 are most likely associated with the 23 percent of hectares in the 1935 sample that retained the DFGF forest type (the tree species most likely to be killed by root disease in this area), and increased canopy closure as indicated by changing to structure class 3. So, the low root level of succession influence, associated with the lower RRSV ratings, was assigned to the pathway DFGF/4 --> DFGF/3 (Table 3.7). At the other extreme of disease severity, 20 percent of hectares in 1935 were observed to have grand fir forest types, with Douglas-fir (the most susceptible of the two species) decreasing relative to the grand fir component. On a little more than half of these hectares, the structure class remained a 4, indicating that canopy closure was prevented. The remaining hectares developed what is probably a root disease patch, having lost virtually all of the large tree component, and ended up in structure class 1 in 1975. Both of these transitions are consistent with severe levels of root disease, corresponding to the 21 percent of hectares in the sample rated as severity levels 6 and 7. The 60 percent of hectares in this class in 1935 were still in the same class in 1975. This was interpreted to be consistent with assignment of moderate levels of root disease severity in the class index values 3, 4, and 5.

Table 3.7: Transitions from one polygon class and associated root disease influence on succession. The overall succession influence of root diseases in this class was moderate.

1935-era Class	1935-era Avg. RRSV	1975-era Class	Proportion	Root Disease Influence Index
HT 4/FT DFGF/SC 4	2.51	FT DFGF/SC 3	21%	Low
		FT DFGF/SC 4	59%	Moderate
		FT GF/SC 1	8%	High
		FT GF/SC 4	12%	High

In most cases, the root disease influenced transitions were easily identified. The greatest difficulty came from some polygon classes having been poorly represented in the 1975 polygon sample, which provided too limited root disease severity statistics. For these, similar polygon classes (in particular, polygon classes that would function similarly for root diseases) were used as a basis for judging the probable distribution of root disease severities in poorly represented classes. For M332a, 8.5 percent of polygon classes observed in 1935 were not represented in the 1975 polygon sample. These 28 polygon classes were assigned influence index values based on adequately sampled polygon classes in ecosection M332a that had similar habitat type group, structure class and a forest types with similar composition of Douglas-fir, grand fir, and subalpine fir.

DOUGLAS-FIR BEETLE INDEX (API) LOGIC

By Sandra Kegley

Ecology of Douglas-fir Beetle

The Douglas-fir beetle is a native bark beetle that infests large diameter, mature Douglas-fir. When populations are low, individual trees or small groups of trees are infested and killed. Infested trees are typically weakened by drought, defoliation, or root disease.

Outbreaks are usually triggered by a large scale windthrow event. Fire-weakened trees or those defoliated by the western spruce budworm or Douglas-fir tussock moth may also contribute to an outbreak. Defoliation events leading to a Douglas-fir beetle outbreak are more common in the dry Douglas-fir habitat types on the east side of the Continental Divide in Region 1 and elsewhere in the West than in ecosections M332a and M333d. These weakened or windthrown trees are extremely attractive to the Douglas-fir beetle, and populations are able to increase rapidly with little or no host resistance. Emerging populations then attack and kill standing green trees. Stand characteristics that contribute to tree susceptibility include density, species diversity, and tree age.

Douglas-fir density can be related to moisture stress which increases tree susceptibility to bark beetles in general. The shaded stem environment of dense stands is also a factor increasing tree susceptibility. Douglas-fir beetles avoid the hot, sun exposed portion of fallen trees and attack the lower boles of standing trees less densely.

Species diversity is another factor contributing to stand susceptibility. Most susceptible stands contain a high percentage of Douglas-fir. The Douglas-fir beetle is also attracted to older trees. The average age of hundreds of Douglas-fir beetle killed trees examined in one study exceeded 120 years (Furniss et al. 1980).

Two different queries were written to account for the behavior differences between low and high beetle populations.

Douglas-fir Beetle Weeding Query

During low populations, the Douglas-fir beetle acts as a weeding agent, taking out the larger diameter, weakened trees in a variety of habitat types. The Douglas-fir beetle most commonly attacks trees at least 14 inches in diameter, although it will occasionally infest smaller trees. Smaller diameter trees are more often infested by woodborers or secondary bark beetles when weakened from root disease or other factors.

The query was designed to pick out all stands with at least one Douglas-fir greater than or equal to 14 inches in diameter. Affects of succession were dependent on the habitat type where mortality occurred. The functions were assigned as outlined in Table 3.8.

Table 3.8: Succession functions of Douglas-fir beetle in sub-outbreak populations.

Indicative Conditions	Function Description	Function Code
Non Douglas-fir forest type with Douglas-fir habitat type	Maintains seral components of stand	S
Non Douglas-fir forest type with subalpine fir habitat type	Climax species composition produced at faster rate	C
Non Douglas-fir forest type with grand fir, western hemlock or subalpine fir habitat type	Climax species composition produced at faster rate	C
Douglas-fir forest type with subalpine fir habitat type	Climax species composition produced at faster rate	C
Douglas-fir forest type with grand fir, western hemlock or subalpine fir habitat type	Climax species composition produced at faster rate	C
Douglas-fir forest type with Douglas-fir habitat type	Set succession back to earlier structural stage	R
Other combinations	No function.	0

Douglas-fir Beetle Outbreak Query

The outbreak query was based on a hazard rating system developed by Thier in southern Idaho (Weatherby and Thier 1992). That hazard rating is based on stand basal area, proportion of the stand BA in Douglas-fir, average stand age, and average diameter of Douglas-fir sawtimber. The hazard rating system identifies stands with mature trees that would most likely be attacked and killed by the Douglas-fir beetle during an outbreak. Although an outbreak trigger event is not included in this query (Table 3.9), we can assume such an event occurs at least once every decade. The hazard rating's attributes, ranges, and rating are as follows:

Table 3.9: Action probability indices for outbreak-type actions of Douglas-fir beetle.

Attribute	Attribute Values	Index value
Stand basal area (sq.ft./acre)	<120	0.5
	GE120, <250	1.0
	GE 250	1.5
% stand basal area which is Douglas-fir	<25	1.0
	GE 25, <50	2.0
	GE 50	3.0
BA-weighted average stand age	<80	1.0
	GE 80, <120	2.0
	GE 120	2.0
Average DBH of Douglas-fir >8" DBH	<10	1.0
	GE 10, <14	2.0
	GE 14	3.0

The stand hazard rating is obtained by summing attribute index values (Table 3.10). Low hazard stands have ratings ranging from 0-4, moderate hazard stands have ratings ranging from 5-7, and high hazard stands have ratings ranging from 8-11.

The script was designed to sort stands by age class, diameter, percent basal area in Douglas-fir, and total basal area of the stand. Low hazard attributes were not included because the probability of group mortality was low, and also because low hazard conditions were mostly covered in the Douglas-fir beetle weeding query. All stands not rated in this query would be given a value of L (low) for the Douglas-fir beetle group probability. Hazard rating values were assigned and summed according to Weatherby and Thier.

Table 3.10: Hazard rating values for Douglas-fir beetle group activity.

			Hazard Rating	
Ave. DBH Douglas-fir	**Douglas-fir % of Total BA**	**Total BA (square feet)**	**Age GE 80, <120**	**Age GE 120**
10 -13.9"	GE 25, <50	GE 80, <120	M	
		GE 120, <250	M	H
		GE 250	M	H
	GE 50	GE 80, <120	M	H
		GE 120, <250	H	H
		GE 250	H	H
GE 14"	GE 25, <50	GE 80, <120	M	H
		GE 120, <250	H	H
		GE 250	H	H
	GE 50	GE 80, <120	H	H
		GE 120, <250	H	H
		GE 250	H	H

MOUNTAIN PINE BEETLE IN LODGEPOLE PINE; QUERY LOGIC

By Carol Bell Randall

General Overview

The mountain pine beetle, *Dendroctonus ponderosae* Hopk., is a native bark beetle whose depredations can have major impacts on succession in ecosystems with lodgepole pine. Successful mountain pine beetle attacks kill lodgepole pine.

Not all lodgepole pine trees are equally likely to be successfully attacked. Mature, large diameter (and thick phloem) trees receive the most attacks in a given stand. Some trees within a given size and age class are able to resist beetle attacks. As trees become older than about 50 years, the proportion of trees in a given stand able to resist beetles, if attacked, generally decreases with tree age. The beetles attack the lodgepole pines of largest diameter each year of the infestation until mostly small-diameter lodgepole pines remain when the infestation stops.

This query is based upon a method for predicting stand susceptibility developed by Amman et al. (1977). Amman's method uses three stand characteristics to determine the susceptibility of the lodgepole pine component to mountain pine beetle attacks: average age of the lodgepole component, average diameter of the lodgepole component, and the location of the stand as characterized by elevation and latitude (Table 3.11).

Table 3.11: Predicting Stand Susceptibility (Amman et al. 1977).

Elevation/Latitude Factor		Average age of LP (years) (BA-weighted)		Average DBH LP (BA-weighted)	
Value	Index	Value	Index	Value	Index
High	1	< 60	1	< 7"	1
Moderate	2	GE 60, <80	2	GE 7, <8"	2
Low	3	GE 80	3	GE 8"	3

In order to be susceptible to a beetle epidemic, a lodgepole pine stand must be located at an elevation and latitude where climate is favorable to the beetle. Even if a lodgepole pine stand is in an elevation and latitude section of potentially heavy beetle damage, the stand must meet other requirements for the beetle to be successful. In general, stand age must be 80 years or more, and the average DBH of a stand for trees 5 inches and larger must exceed 8 inches.

By multiplying the following risk factors (1 = low, 2 = moderate, 3 = high) or elevation and latitude, average age, and average DBH, the stand's susceptibility classification is obtained: low = 1 to 9; moderate = 12 to 18; high = 27.

Justification for the Amman et al. (1977) Susceptibility Index

Susceptibility refers the ability of a stand to support a growing population of mountain pine beetles. It is determined by two factors: the quality and the quantity of susceptible lodgepole pine. The quality of the lodgepole pine component of a stand is best characterized by the phloem thickness. Phloem is the food of developing mountain pine beetle larvae. The amount of phloem

is one of the most important factors determining the number of larvae that will complete development, become adults, emerge to attack new trees, and establish the next generation. On the average the thicker the phloem, the greater will be the ratio of brood adults to parents that infested and killed the trees. Phloem thickness is not routinely measured as part of a stand exam, however it is correlated with other tree measurements such as tree age and diameter.

The mountain pine beetle kills proportionately more large than small diameter trees. Beetle production is low in small diameter trees because they generally have thin phloem, which dries quickly following an attack. Losses range from a small proportion of trees 4 inches in DBH. to a large proportion of trees over 10 inches DBH. Beetles prefer the largest, greenest trees left in the stand each year as the infestation progresses. After the beetles have killed most large-diameter trees, they infest some of the remaining small-diameter trees. Few beetles mature and emerge from these small-diameter trees so the population declines.

Infestations of the beetle seldom develop in stands less than 60 years of age. This is partially due to trees being of small size and having generally thin phloem. The more resinous phloem found in these trees may also be a contributing factor. Trees less than 60 years old may be infested, but when they are there is only slight danger that the outbreak will develop to epidemic proportions. In the 60- to 80-year age category, a larger proportion of the trees have reached diameters conducive to more severe and sustained beetle infestations. In these trees, phloem is thicker, and its physical and perhaps chemical characteristics are better for beetle development. Stands more than 80 years of age present the greatest potential for beetle infestation. Stands having a large proportion of large diameter trees with thick phloem are most likely to be infested and will suffer proportionately greater losses.

A stand factor that impacts the quality of lodgepole for mountain pine beetle colonization is location. With increased elevation, tree losses to the mountain pine beetle decline. The cool climate of high elevations slows beetle development; during the longer development periods, beetle mortality is higher, thus reducing populations more than when development proceeds normally. In assessing the effect of temperature on the beetle and its potential to kill trees, both elevation and latitude of a lodgepole pine stand must be considered. Accordingly, Hopkin's Bioclimatic Law applies: variation in seasonal development and habits of plants and animals at different geographical positions within the range of their distribution is at the rate of 4 days for each degree of latitude, 5 degrees of longitude, or 400 feet of elevation).

The second factor that should be considered when determining the susceptibility of a stand to mountain pine beetle attack is the quantity of lodgepole pine. In the system proposed by Amman et al. (1977) quantity is not incorporated.

The Mountain Pine Beetle in Lodgepole Pine Query

This query is based on Amman et al. (1977) susceptibility index; however, it does consider quantity of lodgepole pine. The query first sorts out stands with more than 25 percent basal area in lodgepole pine. The successional development of a stand with less than 25 percent lodgepole pine basal area is not likely to be seriously impacted by the beetle and was assigned a susceptibility value of 0. Further inferences about the quantity of lodgepole in a particular stand may be made by considering the forest type of the stand. Next, the query sorts stand by the age of the lodgepole pine component: LPP greater than 80 years of age, LPP greater than or equal to 60 years of age, LPP less than 60 years of age. Within these three age classifications, the query sorts stands by the average diameter of the lodgepole pine into three sub classes: greater than 8 inches, greater than or equal to 7 inches, and less than 7 inches.

Almost all lodgepole stands within the Nez Perce, Clearwater, Idaho Panhandle, Flathead, Lolo, and Kootenai National Forest occur on sites that fall within the high hazard location category for the Amman et al. (1977) system. As a result, no attempts were made in this query to address the location aspect of the susceptibility index. As different portions of the region are assessed, the assumption that the location aspect of the susceptibility index will be high will need to be re-evaluated.

The stands are classified according to low, moderate, or high susceptibility (Table 3.12).

Table 3.12: Stand susceptibility rating for mountain pine beetle in lodgepole pine.

Average Age of LP (BA-weighted)	Average DBH of LP (BA-weighted)	Susceptibility Rating*
GE 80 Years	GE 8"	3 (High)
	GE 7", <8"	2 (Moderate)
	<7"	1 (Low)
<80 Years, GE 60	GE 8"	2 (Moderate)
	GE 7", <8"	2 (Moderate)
	<7"	1 (Low)
<60 Years	GE 8"	1 (Low)
	GE 7", <8"	1 (Low)
	<7"	1 (Low)

*Within the Oracle table LA_IP_CURRENT susceptibilities are denoted by numbers, with 0 = not susceptible, 1 = low susceptibility, 2 = moderate susceptibility, 3 = high susceptibility.

The Lodgepole Pine Role Query

The susceptibility index for mountain pine beetle tells only part of the successional story. In order to understand the role that mountain pine beetle may play in the succession of a stand with susceptible lodgepole pine, it is important to understand the successional role that lodgepole pine plays.

There are four commonly recognized successional roles for lodgepole pine: minor seral, dominant seral, climax, and persistent (Pfister and Daubenmire 1975). Mountain pine beetle may be found killing lodgepole pine in any of these roles. The beetles' impact on lodgepole pine does not usually result in an alteration of stand succession unless lodgepole pine is a major stand component (Amman 1977). The successional role of lodgepole pine has been characterized by habitat types (Table 3.13).

Table 3.13: Lodgepole pine successional role as determined by habitat type.

Habitat Types where Lodgepole Pine is a Minor Seral	Habitat Types where Lodgepole Pine is a Dominant Seral	Habitat Types where Lodgepole Pine is Persistent or Climax
220, 226, 260, 261, 262, 263, 282, 291, 300, 310, 311, 312, 313, 508, 516, 517, 518, 520, 521, 522, 523, 524, 525, 526, 529, 530, 531, 533, 534, 535, 545, 546, 547, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 590, 591, 592, 635, 636, 637, 710, 711, 712, 713, 770, 830, 831, 840, 841, 842	250, 280, 281, 283, 290, 292, 293, 320, 322, 323, 360, 400, 420, 421, 422, 430, 440, 450, 470, 480, 510, 511, 512, 515, 620, 621, 622, 623, 624, 625, 630, 650, 651, 652, 653, 654, 655, 660, 661, 662, 663, 670, 671, 672, 673, 674, 675, 676, 677, 680, 681, 682, 685, 686, 687, 690, 692, 693, 694, 720, 730, 731, 732, 733, 740, 750, 780, 790, 791, 792, 820, 821, 850	640, 900, 910, 920, 925, 930, 940, 950

Data from Cooper et al. (1991) and Pfister et al. (1977).

Lodgepole pine as minor seral

Where it plays a minor seral role, lodgepole pine is most commonly a minor component of young, even age, mixed conifer stands. It is replaced by shade-tolerant associates in 50 to 200 years; the more mesic the site, the sooner replacement occurs. On some habitat types where lodgepole plays a minor seral role, fire has allowed the species to dominate a stand. In these situations the lodgepole overstory tends to open up within 100 to 120 years, allowing succession to more shade-tolerant species to progress.

Lodgepole pine as dominant seral

Lodgepole pine is often the dominant forest type of even-age stands in habitat types where it plays a dominant seral role. Often the lodgepole forests occurs with a vigorous understory of shade-tolerant species that will replace lodgepole in 100 to 200 years. Succession occurs most rapidly where lodgepole pine and shade-tolerant associates become established simultaneously. Lodgepole pine gains dominance through rapid early growth, but shade-tolerant species persist and assume dominance as lodgepole pines die.

Lodgepole pine as persistent and/or climax

In stands where lodgepole pine plays a persistent successional role, it forms the dominant forest type of an even-age stand with little evidence of replacement of shade-tolerant species. The shade-tolerant species occur only as scattered individuals and apparently are too few and lack sufficient vigor to replace lodgepole pine. Lodgepole pine maintains dominance either because of inadequate seed source for potential competitors or because the sites are poorly suited for other species. Where lodgepole is climax, it is the only species capable of growing and self-

perpetuating on the site. Usually these sites occur in frost pockets or on areas where the soil is not capable of supporting other species.

THE MOUNTAIN PINE BEETLE AND WESTERN PINE BEETLE IN PONDEROSA PINE: QUERY LOGIC

By Carol Bell Randall

General Overview

The mountain pine beetle (MPB), *Dendroctonus ponderosae* Hopk., and western pine beetle (WPB), *Dentroctonus brevicomis*, are the two most destructive bark beetles that attack ponderosa pine in the United States. Successful beetle attacks kill the host.

The mountain pine beetle typically kills groups of ponderosa pines, often on a large scale, both in mature and in young overstocked stands. Mostly the mountain pine beetle is a primary tree killer, but at times it occurs as a secondary tree killer: for example, in association with the western pine beetle (Furniss and Carolin 1977). Mountain pine beetle outbreaks are most devastating in stands that are pure or nearly pure ponderosa pine, are essentially even aged, are 50-100 years old, have average DBHs between 8 and 12 in., and have a stem basal area generally in excess of 150 square feet/acre (Sartwell and Stevens 1975).

The western pine beetle devastated stands of large, over-mature, decadent ponderosa pines in the first half of the 20th century. Where stands of this nature still exist, there is great potential for damage. Even single, large, old, slow growing or diseased ponderosa pines are very susceptible to attack. Recently, the western pine beetle has become especially aggressive in second growth stands, killing trees 6 inches or larger in diameter, including apparently healthy trees. Trees are characteristically killed in groups, primarily in dense, overstocked stands of pure, even-aged pines. Drought-weakened trees are especially susceptible, and outbreak populations can build to very high levels under these conditions (Livingston 1991).

This query is based upon a method for predicting the susceptibility of ponderosa pine stands to loss from the mountain pine beetle developed by Stevens et al. (1980) as modified by additional work by Schmid and Mata (1992) in the Black Hills of South Dakota, and incorporates information about the host preferences of the western pine beetle in ponderosa pine from northern Idaho and western Montana. The query (Table 3.14) considers average tree diameter, stand density, and (to a limited degree) size of the ponderosa pine component to derive a stand susceptibility index.

Table 3.14: Predicting stand susceptibility to mountain pine beetle in ponderosa pine (Stevens et al. 1980, Schmid and Mata 1992).

	Susceptibility Classes		
	1 (Low)	2 (Moderate)	3 (High)
Stand Structure	Multi- storied	Two- stories	Single- storied
Average Stand DBH	< 6"	6-10"	> 10"
Stand Density	<180 sq.ft./acre	80-120 sq.ft./acre	> 150 sq.ft./acre

Average tree diameter, stand density, and stand structure are key elements in determining the susceptibility of a ponderosa pine stand to mountain pine beetle according to work done in the Black Hills of South Dakota. Western pine beetle activity has also been demonstrated to be affected by average tree diameter and stand density, though a specific stand susceptibility rating system for this beetle has not been developed. Single storied stands are most susceptible to heavy mountain pine beetle damage. Susceptibility to bark beetle attacks increases with DBH: in the case of mountain pine beetle, reaching a maximum when trees are around 12 inches in diameter, though both western pine beetle and mountain pine beetle will attack larger trees. During the build up of beetle outbreaks, denser stands within a given mean diameter are more susceptible to invasion.

By multiplying the following susceptibility indices (1 = low, 2 = moderate, and 3 = high) for stand structure, average stand DBH, and stand density, the stand's susceptibility classification to the mountain pine beetle is obtained: low = 2-6; moderate = 8-12; high = 18-27. Observations in Idaho suggest that the western pine beetle would also respond to similar conditions in second growth ponderosa pine stands.

Justification for the Stevens et al. (1980) Susceptibility Index

Susceptibility refers to the ability of a stand to support a growing population of bark beetles. It is determined by two factors: the quality and the quantity of susceptible ponderosa pine. Host quality is best characterized by the quality of the tissue where the beetles feed. For the mountain pine beetle, host quality is associated with phloem thickness (as it has been proven in studies with the mountain pine beetle in lodgepole pine (Roe and Amman 1970): and for the western pine beetle host quality is associated with bark thickness (Miller and Keen 1960). The quality of these tissues as a food source for developing beetles will determine the number of larvae that will complete development, become adults, emerge to attack new trees, and establish the next generation. On average, the thicker the phloem for mountain pine beetle and the bark for western pine beetle, the greater will be the ratio of brood adults to parents that infested and killed the trees. Phloem and bark thickness measurements are not taken as parts of stand exams, however they are correlated with other tree measurements such as DBH and stand density.

Stevens et al. (1970) used stand structure, average stand DBH, and stand density to determine overall stand susceptibility to mountain pine beetle in ponderosa pine. They used stand structure because they observed that single-storied ponderosa pine stands tended to receive the most mountain pine beetle damage. For the western pine beetle, there are no studies that address stand structure with regards to western pine beetle mortality; however, most second growth ponderosa pine stands that are heavily impacted by the western pine beetle are relatively single-storied. This does not address, however, the tendency of western pine beetle to attack large, over-mature ponderosa pine that may occur as scattered individuals or groups in mixed conifer or multi-aged ponderosa pine stands.

Average DBH indirectly measures the quality of a stand for bark beetle attacks. It has been shown that there is a correlation between both phloem thickness and bark thickness and a tree's DBH; however, this correlation is not perfect and may be influenced by a number of other factors, such as tree vigor, stand density, and site potential. Studies show that, as mountain pine beetle attacks increase from the endemic phase to the epidemic phase or decrease from the epidemic phase back to the endemic phase, they become more random in nature, and all diameter classes from 7-19 inches are equally susceptible to mountain pine beetle attack. During the epidemic phase, mountain pine beetle attack becomes directed towards trees in the diameter

range of 7-13 inches (Lessard 1981). For the western pine beetle, all trees greater than 6 inches in diameter are susceptible to attack; therefore, as the DBH of the ponderosa pine component increases, risk of beetle outbreak also tends to increase, reaching a maximum when ponderosa pine trees average 12 inches in diameter and larger.

Stand density is another parameter which has been correlated with tree vigor and the quality of ponderosa pine as a host for mountain pine beetle and western pine beetle. During the years a mountain pine beetle outbreak is building to its maximum destructive capacity, the more dense the ponderosa pine stand is within a given mean diameter, the more susceptible it will be to severe losses. Observations in northern Idaho of western pine beetle in dense second-growth ponderosa pine are consistent with these observations for mountain pine beetle (Livingston 1991). This is a direct result of inter-tree competition reducing the ability of ponderosa pine to defend itself from bark beetle attack. At maximum outbreak levels, this pattern is less evident because beetles must attack trees in a variety of conditions.

In addition to host quality, the quantity of susceptible ponderosa pine should be considered when determining stand susceptibility. The susceptibility rating system described was developed in the Black Hills of South Dakota. In the Black Hills ponderosa pine generally forms pure stands and represents the climax species on a site, and the western pine beetle does not occur. In the majority of its range, ponderosa pine is a seral species and often occurs in mixed stands with other species of conifers.

The Mountain Pine Beetle/Western Pine Beetle in Ponderosa Pine Query

This query is based upon the susceptibility rating developed by Stevens et al. (1980) as modified by Schmid and Mata (1992) for the mountain pine beetle and incorporates information on western pine beetle feeding preferences. The query first identifies stands containing at least 25 percent BA ponderosa pine. The successional development of a stand with less than 25 percent ponderosa pine basal area is not likely to be seriously impacted by mountain pine beetle and western pine beetle, and so was assigned a susceptibility value of 0. Further inferences about the quantity of ponderosa pine in a particular stand may be made by considering the forest type of the stand. The query sorts these stands by average stand basal area: stands with <80 BA/ac; stands with between 80 and 120 BA/ac; and stands with >120 BA/ac. Within these three basal area classifications, the query sorts stands by the average diameter of the ponderosa pine into three sub-classes: less than 6 inches; greater than or equal to 6 inches but less than 10 inches; and greater than or equal to 10 inches. The stands are classified as having low, moderate, or high susceptibility (Table 3.15).

Table 3.15: Susceptibility classes of stands to mountain pine beetle effects on ponderosa pine.

Average BA/acre (sq. ft.)	Average DBH of PP (inches)	API Code
LT 80	LT 6	L
	GE 6 and LT 10	L
	GE 10	L
80 to 120	LT 6	L
	GE 6 and LT 10	M
	GE 10	M
GT 120	LT 6	L
	GE 6 and LT 10	M
	GE 10	H

Within the Oracle table LA_IP_CURRENT susceptibilities of the ponderosa pine component are denoted by 0 = not susceptible, L = low susceptibility, M = moderate susceptibility, and H = high susceptibility.

The Ponderosa Pine Role Query

The susceptibility index for the mountain pine beetle and western pine beetle in ponderosa pine tells only part of the successional story. In order to understand the role that these beetles may play in the succession of a stand with susceptible ponderosa pine, it is important to understand the successional role that the ponderosa pine component plays.

There are three commonly recognized successional roles for ponderosa pine: minor seral, dominant seral, and climax (Steele 1988). Beetles may be found killing ponderosa pine in any of these roles. The beetles' impact on ponderosa pine does not usually result in an alteration of stand succession unless ponderosa pine is a major stand component. Ponderosa pine occupies a climax role towards the severe limits of its environmental range and becomes increasingly seral with increasingly favorable environment. The successional role of ponderosa pine has been characterized by habitat types (Table 3.16).

Table 3.16: Ponderosa pine successional role as determined by habitat type (Cooper et al. 1991 and Pfister et al. 1977).

Habitat Types where Ponderosa Pine is a Minor Seral	Habitat Types where Ponderosa Pine is a Dominant Seral	Habitat Types where Ponderosa Pine is Climax
280, 281,283, 290, 291, 292, 293, 300, 507, 516, 518, 520, 521, 523, 525, 530, 531, 533, 540, 542, 545, 546, 560, 570, 571, 574, 575, 578, 620, 624, 690, 693, 710, 712	210, 220, 250, 260, 261, 262, 263, 282, 310, 311, 312, 313, 320, 321, 322, 323, 324, 330, 340, 350, 505, 506, 508, 524, 590, 591, 592	100, 110, 130, 140, 141, 142, 160, 161, 162, 170, 171, 172, 180, 181, 182, 190

Ponderosa pine as a minor seral

Ponderosa pine is considered a minor seral species where it has historically occurred in relatively small numbers and was never more than a minor component of the stand. This may be due to a marginal environment for the pine, or it may also result from extreme conditions on highly productive sites. In either case, the pine has little opportunity to dominate the site at any seral stage.

Ponderosa pine is a minor seral species on a wide variety of habitat types from the hemlock series through the grand fir and Douglas-fir series, and its mere presence in a stand does not always indicate that a pine plantation will be successful. In central Idaho attempts to establish ponderosa pine plantations in habitat types where it plays a minor seral role have failed over the long term even though planting survival was high the first few years. Intense shrub competition, repeated snow damage, and possibly root disease have reverted pine plantations to a minor seral status on many of these sites. On other sites ponderosa pine plantations still dominate, but we do not yet know if they will reach rotation age.

Ponderosa pine as a dominant seral

As a dominant seral, ponderosa pine can dominate the site at some seral stage. Much of the original ponderosa pine forests fell into this category. Fire had a profound effect on the distribution of ponderosa pine in habitat types where it plays a dominant seral role. Although ponderosa pine seedlings are readily killed by fire, larger trees possess thick bark, which offers effective protection from fire damage. Competing tree species, such as Douglas-fir and grand fir, are considerably less fire tolerant, especially in the sapling and pole size classes. Ponderosa pine was therefore able to maintain its position as a dominant seral species on large areas of middle elevation forests in the West. Because of successful fire control over the past 50 years, many of these stands have developed understories of Douglas-fir and true fir. Type conversion has been accelerated by harvest of the ponderosa pine, leaving residual stands composed of true firs, Douglas-fir, and lodgepole pine (Oliver and Ryker 1990).

Ponderosa pine is a dominant seral on portions of the grand fir series and Douglas-fir series.

Ponderosa pine as a climax species

The amount of area where ponderosa pine is climax is considerably less than where it is seral. Sites where ponderosa pine is climax typically occur within the lower forest zone where it grades into non-forest communities. Climax ponderosa pine communities can be visualized as a

transition between forest and non-forest. These sites tend to be the least favorable for ponderosa pine in terms of establishment and growth, but are the most favorable in terms of competition.

Ponderosa pine is the climax species on the ponderosa pine series.

MOUNTAIN PINE BEETLE IN WESTERN WHITE PINE QUERY LOGIC

By Sandra Kegley

Background

A formal hazard rating system for mountain pine beetle in western white pine has not yet been developed. However, from current surveys of mountain pine beetle in western white pine and from historic reports, we do know some characteristics of white pine trees that make them more susceptible to beetle attack.

Outbreaks of mountain pine beetle in western white pine were reported as early as 1910. At that time, the component of mature white pine in western forests was much greater than it is today, and outbreaks of the mountain pine beetle much more prevalent. However, we still currently find mountain pine beetles attacking mature and overmature western white pine.

White pine mortality from mountain pine beetle attack becomes noticeable in stands over 70 years old (Terrell 1961). In 1940-41, a study was conducted to determine the susceptibility of western white pine stands to mountain pine beetle attack. Plots were taken in white pine stands of various age and site classes in the Kootenai, Kaniksu, Coeur d'Alene, and Clearwater National Forests. Stand BA ranged from 140 to 200 quare feet per acre. Percentage white pine ranged from 40 to 60 percent, and age classes from 80 to 190 years. White pine mortality ranged from 12 to 15 percent in age classes 80 to 160 with stand BA from 140 to 165. Mortality increased to 18 to 26 percent in age classes 160 to 90 with stand BA from 185 to 200 (Terrell 1961). More recent surveys of mountain pine beetle in western white pine have found beetle attacks in trees as small as 8 inches in diameter and in stands with much lower percentages of western white pine. However, most of the damage still occurs in mature and overmature white pine in stands with high basal areas.

Query

The query (Table 3.17) was designed to account for tree age, diameter, percentage basal area western white pine, and stand basal area, similar to hazard ratings developed for Douglas-fir beetle and spruce beetle (Weatherby and Thier 1993, Schmid and Frye 1976). Each attribute was given a value (in parentheses) and summed to produce a hazard code.

Table 3.17: Criteria used to assign the action probability index number for mountain pine beetle effects in western white pine.

			Age of Western White Pine (BA-weighted)	
DBH (in.) of Western White Pine	% BA Western White Pine	Total BA (sq.ft.)	70 -159	GE 160
			API Code	
GE 8, LT 12	GE 0, LT 25	GE 80, LT 140	4	5
		GE 140, LT 180	5	6
		GE 180	6	7
	GE 25, LT 50	GE 80, LT 140	5	6
		GE 140, LT 180	6	7
		GE 180	7	8
	GE 50	GE 80, LT 140	6	7
		GE 140, LT 180	7	8
		GE 180	8	9
GE12, LT 16	GE 0, LT 25	GE 80, LT 140	5	6
		GE 140, LT 180	6	7
		GE 180	7	8
	GE 25, LT 50	GE 80, LT 140	6	7
		GE 140, LT 180	7	8
		GE 180	8	9
	GE 50	GE 80, LT 140	7	8
		GE 140, LT 180	8	9
		GE 180	9	10
GE 16	GE 0, LT 25	GE 80, LT 140	6	7
		GE 140, LT 180	7	8
		GE 180	8	9
	GE 25, LT 50	GE 80, LT 140	7	8
		GE 140, LT 180	8	9

		GE 180	9	10
	GE 50	GE 80, LT 140	8	9
		GE 140, LT 180	9	10
		GE 180	10	11

Hazard codes can then be grouped as follows: 4-5: low hazard (L) with expected white pine mortality rates less than 12 percent, 6-8: moderate hazard (M), with 12-15 percent mortality rates, and 9-11: high hazard (H), with greater than 15 percent mortality rates.

DWARF MISTLETOES: ASSIGNING THE APIs

By Jane Taylor

The query logic for assigning the action probability indices for dwarf mistletoes was designed to identify polygons where and species of dwarf mistletoe had potential for causing effects that would be significant enough to alter successional patterns. Logic for the query was based on information gathered from published reports on mistletoe population dynamics, tree mortality, and tree growth and yield impacts.

Criteria Used to Assign Dwarf Mistletoe APIs

Tree species

The dwarf mistletoes of concern are generally host specific: the principal host of *Arceuthobium laricis* is western larch, the principal host of *A. americanum* is lodgepole pine, and the principal host of *A. douglasii* is Douglas-fir. Although all three of these dwarf mistletoe species can sometimes parasitize other conifer hosts, the polygons in which dwarf mistletoe would most likely cause a significant effect on succession are those with a high percentage of the principal host species (Hawksworth and Wiens 1996). The query begins by searching for polygons with the dwarf mistletoe host present in any quantity. Next, the polygons selected with some host present are broken into those polygons in which the host is the basal area (BA) plurality (host forest type) and those polygons in which the host species is not the BA plurality (non-host forest type).

Host species age

Generally speaking, the longer a tree has been infected with dwarf mistletoe the greater the disease effects will be. The next step in the query is to break polygons out by age of the principal host tree species. The justification was based on what is known about how mistletoes spread and intensify within trees and throughout stands over time.

The six-class dwarf mistletoe rating system is a numerical system used to identify dwarf mistoletoe infection levels in individual trees and stands (Hawksworth 1977). The system assigns a dwarf mistletoe rating (DMR) to each tree ranging from 1-6 based on how much of the tree crown appears to be infected: 1 = most lightly infected, and 6 = most heavily infected. The stand DMR is the average of the DMRs of all individuals in the stand.

Initial infection of seedlings generally occurs at about 10-20 years of age (Mathiasen et al. 1990, Hawksworth and Graham 1963). Dwarf mistletoes intensify within tree crowns and spread to other trees relatively slowly over time. Hawksworth and Hinds (1964) reported that the average stand DMR increased about one DMR level each 14 years in single-storied stands that were 15-60 years old. The increase was slightly slower in younger stands and slightly faster in older stands. Significant height and diameter growth impacts, as well as effects on cone and seed production, do not occur until trees reach a DMR of 4-6 (Hawksworth et al. 1995). Once a tree reaches a DMR of 6, meaning virtually 100 percent of the crown is infected, it takes at least 10 years for mortality to occur, and usually more (Hawksworth and Geils 1990). If a significant proportion of trees in a stand are infected by age 20, and it takes an additional 60 years to reach an average stand DMR of 4, plus an additional 10-20 years (minimum) for tree mortality to begin, then it would take a minimum of 100 years for dwarf mistletoe to produce noticeable effects of succession. The minimum age of 100 years was used in the Douglas-fir query. To account

for differences in growth rates and differences in the timing of growth slow-down between the different tree species, this minimum age threshold was decreased slightly to 90 years for lodgepole pine and increased slightly to 120 years for western larch.

Stand structure

Dwarf mistletoe spread and intensification, as well as the disease effects, are greater in multi-storied stands than in single-storied stands. Mistletoe seeds from infected overstory trees "rain down" on susceptible understory trees. Many of the seedlings and saplings growing under a heavily infected overstory will die before reaching maturity. The last step in the query is to account for differences in dwarf mistletoe effects relative to differences in stand structure. The query identifies multi-storied polygons as those which have a host species component at least 90-120 years old (depending on the species) and at least 100 trees per acre of the principal host less than 5 inches in diameter at breast height.

Oracle SQL-Plus Queries to Assign APIs for Dwarf Mistletoes

The query was designed for the three major dwarf mistletoe species found in the region: lodgepole pine dwarf mistletoe (Table 3.18), Douglas-fir dwarf mistletoe (Table 3.19), and western larch dwarf mistletoe (Table 3.20). Each script is run separately for each dwarf mistletoe species, and the resulting API value updates the respective field in the Oracle table LA_IP_CURRENT.

Table 3.18: Query structure for lodgepole pine dwarf mistletoe.

First Criterion	Plurality of BA	Age of Stand (BA-weighted)	TPA of Lodgepole Pine LP 5" DBH	API Code
Lodgepole pine present in stand	Lodgepole pine	GE 90	GE 100	6
			<100	5
		<90		4
	Other species	GE 90	GE 100	3
			<100	2
		<90		1

Table 3.19: Query structure for Douglas-fir dwarf mistletoe.

First Criterion	Plurality of BA	Age of Stand (BA-weighted)	TPA of Douglas-fir LT 5" DBH	API Code
Douglas-fir present in stand	Douglas-fir	GE 100	GE 100	6
			<100	5
		<100		4
	Other species	GE 100	GE 100	3
			<100	2
		<100		1

Table 3.20: Query structure for western larch dwarf mistletoe.

First Criterion	Plurality of BA	Age of Stand (BA-weighted)	TPA of WL LT 5" DBH	API Code
Western larch present in stand	Western larch	GE 120	GE 100	6
			<100	5
		<120		4
	Other species	GE 120	GE 100	3
			<100	2
		<120		1

Interpreting Dwarf Mistletoe Index Values

The array index values range from 1-6, with 1 being the lowest value, and 6 being the highest. Basically, the array value increases as percent of host trees present in the polygon increases, as stand age increases, and as the probability of a multi-storied stand condition increases.

STEM DECAYS ACTION PROBABILITY INDEX

By I. Blakey Lockman

Introduction

The infection cycles of most heartwood stem decay fungi have not been well documented in the literature, but the severity and frequency of most decays appear to increase with an increase in host age (Boyce and Wagg 1953, Hepting 1971, Faull 1919). This correlation between host age and heartwood stem decay is related to the formation of heartwood in trees. Stem decays in live trees generally affect only the heartwood. Heartwood formation is influenced by the age, vigor, and species of tree involved. Older trees and suppressed trees have higher heartwood/sapwood ratios. Older trees are also more likely to have experienced wounding. Wounds are thought to be needed by stem decay fungi to gain entry into trees or to activate decay, as in the case of *Echinodontium tinctorium* Ell. and Ev.

Stem Decay Query Logic

The queries were designed to identify stands in which stem decays have the highest potential for influencing the structural development of the stand and possibly influencing successional patterns. The query was separated into three components based on the fungi responsible for the decay and the species of host affected.

Stem decay caused by *Echinodontium tinctorium* (Indian paint fungus)

The query logic is based on the infection cycle of *Echinodontium tinctorium*, which is the primary cause of stem decay in grand fir, subalpine fir, western hemlock, and mountain hemlock (Hepting 1971). The fruiting bodies of the fungus are usually formed at the base of branches on susceptible host species. Spores produced by the conk rain down on the susceptible understory and infect small branchlet stubs just before they are overgrown. Trees must be at least 40 years old before branchlet stubs are formed. Suppressed and slow-growing trees heal these branchlet stubs very slowly, thus allowing more time for infection by *E. tinctorium*. After the spores have infected the branchlet stubs, they germinate and grow within the branch until the branchlet is overgrown by the expanding bole, at which time the fungus then goes dormant for up to 50 years. Dormant infections are activated immediately by nearby wounds that allow air into the heartwood. After extensive decay has formed from these activated infections, fruiting bodies of the fungus are formed, and the infection cycle has been completed (Filip et al. 1983).

A study on estimating decay in 40- 90-year-old grand fir stands was completed on the Clearwater National Forest in 1988 (Filip et al. 1990). Information from this study and discussion with one of the researchers indicate the two most significant stand characteristics for determining the amount of stem decay in a stand are stand age and stand structure. Decay is positively correlated with stand age, and stands that have an overstory of grand fir and an understory of grand fir (at least 40 years old) have more decay than single-storied stands.

This query (Table 3.21) separates out stands that are of the susceptible forest types to *E. tinctorium*: grand fir, subalpine fir, mountain hemlock/alpine fir, and western hemlock. Stands with basal plurality in these forest types are separated based on the percent basal area (BA) in trees greater than or equal to 9 inches in diameter at breast height (DBH)–at four and a half feet. Stands with greater than 85 percent of BA in trees greater than 9 inches DBH in the above forest

types are separated into 2 age classes: 40 to 120 years and more than 120 years. These stands are considered to be single-storied. The older stands have a higher probability of being infected with stem decay, and the assigned APIs reflect this. Stands with more than 30 percent BA in trees greater than or equal to 9 inches DBH are separated into three age classes: 0-40 years, 40-120 years, and 120+ years. These stands are considered to be single-storied. Again, older stands have a higher probability of being infected with stem decay, and this is reflected in the APIs. Stands with more than 30 percent and less than 85 percent of basal area in trees greater than or equal to 9 inches DBH are separated into two size classes (greater or equal to 9 inches DBH and less than 9 inches DBH) and three age classes for each size class (0-40 years, 40-120 years, 120+ years). These stands are considered to be two-storied. An older understory with an older overstory has the highest probability of being infected with stem decay. The younger the understory/overstory combination, the lower the probability of being infected, although the two-storied stands have higher stem decay APIs than any of the single-storied stands.

Table 3.21: Criteria for assigning API values for *Echinodontium tinctorium*-caused decay.

		BA- weighted Average Age			
BA Plurality Species	**% Total BA***	**Total Stand Age**	**Overstory Age (GE 9" DBH)**	**Understory Age (< 9" DBH)**	**API Code**
GF, SAF, MAF, or WH	< 30	GE 0, <40			1
		GE 40, <120			4
		GE 120			5
	GE 30, <85		GE 40, <120	GE 0, <40	6
			GE 40, <120	GE 40, <120	7
			GE 40, <120	GE 120	8
			GE 120	GE 0, <40	9
			GE 120	GE 40, <120	10
			GE 120	GE 120	11
	GE 85	GE 0, <40			1
		GE 40, <120			2
		GE 120			3

Stem decay caused by *Phellinus pini*

The majority of stem decay in lodgepole pine, western white pine and Engelmann spruce is caused by *Phellinus pini* (Thore: Fr.) Pilat. (Basham and Morawski 1964, Percival 1933). The infection cycle of *P. pini* has not been well documented in the literature, but the severity and frequency of decay appears to increase with an increase in host age (Boyce and Wagg 1953). The query is broken down into three age classes for the aforementioned tree species: 0 80 years, 80 120 years, and 120+ years (Table 3.22).

Table 3.22: Criteria for assigning the API values for *Phellinus pini*-caused stem decay.

BA Plurality Species	Average Age (years) (BA-weighted)	API Value
LP or WP	GE 0, <80	1
	GE 80, <120	2
	GE 120	3

The APIs do not represent linear increases in the potential for stem decay to occur, only relative increases. For example, a stand with an API of 3 is not three times more likely to have stem decay as a stand with an API of 1, but the potential for stem decay to occur is greater in a stand with an API of 3 than in a stand with an API of 1 or 2.

Stem decay in other tree species

Phellinus pini and *Fomitopsis officinalis* (Vill.: Fr.) Bond. et Sing. are responsible for much stem decay in western and alpine larch, ponderosa pine, Douglas-fir, and whitebark pine (Hepting 1971, Boyce and Wagg 1953). The most common stem decay in western redcedar is caused by *Poria sericeomollis* (Rom.) Engel. (Hepting 1971). The severity and frequency of stem decay from these fungi and other miscellaneous fungi appear to increase with increasing host age. These tree species are generally longer-lived than lodgepole pine, western white pine, and Engelmann spruce, so the spreads between age classes for this query are larger than in the query for *P. pini* stem decay APIs (Table 3.23). Again, the APIs represent relative increases, not linear increases.

Table 3.23: Criteria for assigning the API values for stem decay in western and alpine larch, ponderosa pine, Douglas-fir and/or whitebark pine.

BA Plurality Species	Average Age (years) (BA-weighted)	API Value
DF, WL, WB, PP or C	GE 0, <120	1
	GE 120, <200	2
	GE 200	3

The APIs do not represent linear increases in the potential for stem decay to occur, only relative increases. For example, a stand with an API of 3 is not three times more likely to have stem decay as a stand with an API of 1, but the potential for stem decay to occur is greater in a stand with an API of 3 than in a stand with an API of 1 or 2.

SPRUCE BEETLE API QUERY LOGIC

By Sandra Kegley

The query is based on a hazard rating system developed by Schmid and Frye (1976) in Colorado. The hazard rating includes attributes such as physiographic location, the average diameter of live spruce greater than 10 inches in diameter, stand basal area, and proportion of spruce in the stand. Each of these attributes is given a numerical value as shown in Table 3.24.

Table 3.24: Criteria for assigning the risk index value for Spruce Beetle.

Attribute	Attribute Values	Index Value
Sites on which spruce are growing	Well-drained sites in creek bottoms	3
	Site index GE 80, <120	2
	Site index GE 40, <80	1
Average diameter of spruce GE 10" DBH	GE 16"	3
	GE 12, <16"	2
	<12"	1
Total stand basal area	GE 150	3
	GE 100, <150	2
	<100	1
Spruce % of total canopy	GE 65	3
	GE 50, <65	2
	<50	1

Attribute values are summed to give an overall stand risk index value which is then translated into a potential outbreak rating as shown in Table 3.25.

Table 3.25: Assigning Spruce Beetle APIs based on risk index values.

Sum of Risk Index Values	Action Probability Index
11 - 12	H (high)
7 - 9	M (moderate)
4 - 5	L (low)

The values of 6 and 10 were considered intermediate values to be placed in the appropriate category based on professional judgement. For the query, information on "well-drained

sites in creek bottoms" was difficult to obtain so it is temporarily omitted. With better access to Digital Elevational Model (DEM) data, the query will have the additional risk values added to reflect the influence of site topography. Site indexes for spruce on different habitat types were obtained from Forest Habitat Types of Northern Idaho: A Second Approximation (Cooper et al. 1991). These were lumped into the habitat type groups currently used by the Northern Region in the Biophysical Classification System for northern Idaho and western Montana (Applegate et al. 1996).

A lower limit of 10 percent spruce in the stand was used to eliminate stands with very little Engelmann spruce in which no cover type or structure class would result from action of the spruce beetle. The query which uses habitat type (HT) groups to model physiographic locations is illustrated in Table 3.26.

Table 3.26: Spruce beetle query structure to assign risk index values and APIs.

HT Group	*I	Ave. DBH Spruce GE 10"	I	Spruce % of Total Canopy	I	Stand BA	I	Sum I	** API
3, 4, 8, 9	1	< 12"	1	GE 10, <50	1	<100	1	4	L
	1		1			GE 100, <150	2	5	L
	1		1			GE 150	3	6	L
	1		1	GE 50, <65	2	<100	1	5	L
	1		1		2	GE 100, <150	2	6	L
	1		1		2	GE 150	3	7	M
	1		1	GE 65	3	<100	1	6	L
	1		1		3	GE 100, <150	2	7	M
	1		1		3	GE 150	3	8	M
	1	GE 12, <16"	2	GE 10, <50	1	<100	1	5	L
	1		2		1	GE 100, <150	2	6	L
	1		2		1	GE 150	3	7	M
	1		2	GE 50, <65	2	<100	1	6	L
	1		2		2	GE 100, <150	2	7	M
	1		2		2	GE 150	3	8	M
	1		2	GE 65	3	<100	1	7	M
	1		2		3	GE 100, <150	2	8	M
	1		2		3	GE 150	3	9	M
	1	GE 16"	3	GE 10, <50	1	<100	1	6	M

	1		3		1	GE 100, <150	2	7	M
	1		3		1	GE 150	2	8	M
	1		3	GE 50, <65	2	<100	1	7	M
	1		3		2	GE 100, <150	2	8	M
	1		3		2	GE 150	3	9	M
	1		3	GE 65	3	<100	1	8	M
	1		3		3	GE 100, <150	2	9	H
	1		3		3	GE 150	3	10	H
5, 6, 7	2	< 12"	1	GE 10, <50	1	<100	1	5	L
	2		1		1	GE 100, <150	2	6	L
	2		1		1	GE 150	3	7	M
	2		1	GE 50, <65	2	<100	1	5	L
	2		1		2	GE 100, <150	2	7	M
	2		1		2	GE 150	3	8	M
	2		1	GE 65	3	<100	1	7	M
	2		1		3	GE 100, <150	2	8	M
	2		1		3	GE 150	3	9	M
	2	GE 12, <16"	2	GE 10, <50	1	<100	1	6	L
	2		2		1	GE 100, <150	2	7	M
	2		2		1	GE 150	3	8	M
	2		2	GE 50, <65	2	<100	1	7	M
	2		2		2	GE 100, <150	2	8	M
	2		2		2	GE 150	3	9	H
	2		2	GE 65	3	<100	1	8	M
	2		2		3	GE 100, <150	2	9	H
	2		2		3	GE 150	3	10	H
	2	GE 16"	3	GE 10, <50	1	<100	1	7	M
	2		3		1	GE 100, <150	2	8	M
	2		3		1	GE 150	3	9	M

	2		3	GE 50, <65	2	<100	1	8	M
	2		3		2	GE 100, <150	2	9	H
	2		3		2	GE 150	3	10	H
	2		3	GE 65	3	<100	1	9	M
	2		3		3	GE 100, <150	2	10	H
	2		3		3	GE 150	3	11	H

* Index value for the stand attribute. The index values are added across the row to obtain the sum of index values. The index values are assigned API codes according to their relative probability of successionally significant actions.

** For the intermediate values 6 and 10, all values of 10 were considered high hazard. Values of 6 were considered low or moderate hazard depending on other attribute values. Some values of 9 were changed from moderate to high hazard based on other attributes and professional judgement.

WESTERN SPRUCE BUDWORM API ASSIGNMENT

By Nancy Campbell

Introduction

This query is designed to identify polygons that are susceptible to budworm infestations and associated damage. The probability of budworm defoliation is dependent upon site and stand characteristics and habitat type, which are all components of this query.

The query first sorts stands based upon the percent basal area (BA) in host species. It separates out three primary host types by sequentially sorting stands into the following categories: greater than or equal to 80 percent BA Douglas-fir; greater than 50 percent BA Douglas-fir and/or grand fir; greater than or equal to 80 percent BA subalpine fir. Because of the sequential sorting of categories, no stand can fall into more than one category. Within each of these categories the query then looks at stand vertical structure using the following criteria: Multi-storied; defined as at least 200 trees per acre that are greater than 3 inches DBH and less than 12 inches DBH and at least 20 trees per acre that are less than or equal to 3 inches DBH, and at least 20 percent of the trees which are greater than 5 inches DBH are also greater than or equal to 12 inches DBH. Single and two-storied stands are defined as having at least 200 trees per acre that are greater than 3 inches DBH.

Once the stands have been sorted, they are assigned a relative damage susceptibility value on a scale from 0 (not susceptible) to 8 (very susceptible) (Table 3.27). This index, the action probability index, refers to the likelihood that trees within the stand will experience sufficient damage in the form of top kill, dramatic growth reduction, or outright mortality to alter the course or timing of succession.

Table 3.27: Assigning the action probability index for western spruce budworm.

Species Composition	Stand Structure	Action Probability Index
Douglas-fir GE 80% of total BA	Multi-storied	8
	Single- or two-storied	7
Douglas-fir and grand fir GE 50% of total BA	Multi-storied	6
	Single- or two-storied	5
Subalpine fir GE 80% of total BA	Multi-storied	4
	Single- or two-storied	0
All other combinations of species composition	All structures	0

Stand characteristics. Stand characteristics play an important role in the susceptibility of a forest to damage from budworm. The method outlined above addresses the influence of host

Stand characteristics

Stand characteristics play an important role in the susceptibility of a forest to damage from budworm. The method outlined above addresses the influence of host composition, stand structure, and density as they relate to a stand's relative susceptibility to budworm.

Host species

The principal hosts of budworm are interior Douglas-fir, grand fir, Engelmann spruce, subalpine fir, and western larch. Susceptibility of host species differs considerably depending upon geographical location and habitat type. In mixed host-species stands, the most shade-tolerant host species usually sustains the greatest damage.

Stand composition

Stand susceptibility to infestation and damage are both directly related to the proportion of host species in a stand and the proportion of climax or late successional host species represented. The most susceptible species composition is pure stands of climax host trees. For example, Douglas-fir is most susceptible on warm, dry sites where it often appears in pure, climax stands; it is in these stands where most mortality occurs.

Crown-class structure

The crown-class structure of stands affects budworm population dynamics. Intermediate and understory trees intercept larvae as they spin down or drop from the upper canopy. If the understory trees are host species, the falling larvae can establish a feeding site, complete development, and contribute to succeeding generations. Moreover, if these understory trees are suppressed, they may be producing foliage that is high quality food for the budworm. If no understory trees are present or they are non-host, the dropping larvae will fall to the ground and perish.

Multi-storied stands are generally most susceptible, followed by two- and then single-storied stands. Uneven-aged or multi-storied structures usually receive more damage and mortality than in even-aged stands. The majority of mortality occurs in the intermediate and understory trees.

Stand density

Stand density, in conjunction with stand composition, has an important influence on larval mortality associated with spring and fall dispersal. Such mortality is greater in open stands than in dense stands. Consequently, defoliation increases as crown closure increases. Although higher populations have been found on open-grown trees, more damage was found in closed stands. With other site and stands characteristics held constant, dense stands are more susceptible than open stands. Fore these reasons, stands with less than 200 trees per acre in the 3 to 12 inches diameter class have been assigned a budworm vulnerability index of 0.

Tree and stand maturity

Young seedling stands represent poor habitat for budworm. Rarely are these small trees selected by adult females for egg deposition, and such trees lack the rough bark surfaces used for overwintering. For this reason, all regenerating stands without more than 200 trees greater than 3 inches DBH have been assigned a budworm vulnerability index of 0.

Predicting Stand Susceptibility

The susceptibility index detailed above uses stand composition, structure and density to determine relative stand susceptibility to budworm damage. Because this index only considers stand characteristics, an additional characteristic important in determining risk was added: habitat type.

Studies recently conducted in the Northern Region showed several landscape characteristics to be tightly linked with forests that are highly susceptible to budworm. Habitat type was the second most important factor in determining the probability of an outbreak. Warmer, drier sites were at the highest risk. The amount of continuous climax host type across the landscape was the most important factor.

The habitat type index factors range from -2 to +2. There is not a separate column for this value: it is automatically incorporated into the budworm susceptibility column and displayed in the Oracle table LA_IP_CURRENT. All habitat types were classified according to temperature and moisture. The classification were derived for habitat type groups for northern Idaho, western Montana, and eastern Montana, and from budworm permanent plot information. Stands that occurred on warm, dry habitat types received the highest rating, and those on cool, moist sites received the lowest rating. The adjusted budworm susceptibility index now ranges from 0 to 10, with 10 being the most susceptible.

THE SUCCESSION INFLUENCE INDEX: COMPLEX INTERACTIONS REFLECTED IN APIs

by Susan Hagle

The action probability index (API) is the indicator of the pathogens and insects active in a class of polygons. We know that there is a significant difference in probability that mountain pine beetle will cause changes in a pole-size stand of lodgepole pine as compared to a seedling or sapling stand of lodgepole pine or a pole-size stand of subalpine fir. The API is a means to rank stands based on their relative vulnerability to significant effect by a pathogen or insect. In many cases, there will be more than one insect or pathogen active in a stand at any one point in time. These actions may have opposing or synergistic effects on changes in vegetation. They are also influenced by the interactions among the trees themselves. Although we may not be able to fully appreciate the finer points of these interactions, we can largely capture the outcomes by comparing the APIs for initial polygon classes with the changes in polygon classes through time.

Using the example of mountain pine beetle in lodgepole pine stands, we can see that large-diameter stands of relatively pure lodgepole pine had a relatively high frequency of high and moderate levels of action probability indices. Therefore, this polygon class had a high proportion of stands that offered conditions conducive to maintaining healthy populations of mountain pine beetle. The expected outcome from mountain pine beetle-caused mortality in stands in this class would be a relative reduction in the larger diameter classes of lodgepole pine. Polygon class changes that would result from this outcome would be changes to non-lodgepole pine forest types or those with less significant components of lodgepole pine, and changes to smaller average-tree diameters, shifting from structure class (SC) 3 or 4 to structure class 2 or 1, from SC 2 to SC 1, or reductions in stand density, such as moving from SC 2 or SC 3 to SC 4. The frequency with which these polygon class changes occurred are an indication of how often polygons in classes with relatively high mountain pine beetle APIs actually were significantly influenced by mountain pine beetle. Conversely, if there is no change in cover type or structure class, or if the changes are toward an apparent increase in the relative composition and/or size of lodgepole pine, the mountain pine beetle would be interpreted to have had no significant influence on succession.

In most cases, there were several types of changes observed in a polygon class. For example, in M333d, from starting polygon class HT 7/FT LP/SC 2 there were 10 different outcomes: that is, they ended in 10 different polygon classes forty years later . Similarly, in M332a, 75 percent of polygons that began in class HT 7/FT LP/SC 4 in 1935 had an AFDFLP forest type and structure class 2 forty years later (Table 3.28). The remaining 25 percent followed two other routes, both ending in different forest types, and one showing a loss of the larger tree component as well. The mountain pine beetle API for the polygon class HT 7/FT LP/SC 4 is 12 percent high, 24 percent moderate, and 64 percent low.

Table 3.28: Relative influence of mountain pine beetle in each of the observed successional outcomes after 40 years.

Beginning Polygon Class			Ending Polygon Class				
HT Group	Forest Type	Structure Class	HT Group	Forest Type	Forest Type	Percent of Hectares	Succession Influence of Mountain Pine Beetle
7	LP	4	7	AFDFLP	2	75	High
			7	AFWB	2	16	High
			7	DFLPPP	4	9	Moderate

This approach essentially tests and interprets our hazard rating systems according to actual effect. The new index created by integrating the API and the frequency of congruent changes in polygon class is referred to as the *succession influence*. The succession influence index values were assigned first to each transition pathway in a polygon class. The an overall rating of none, low, moderate, or high was assigned to each polygon class for each pathogen or insect. For a transition pathway, a rating of high (H) for succession influence simply means that both the initial APIs and the subsequent polygon class changes were indicative of a high influence of mountain pine beetle on succession in that initial polygon class. The overall rating for mountain pine beetle in polygon class HT 7/FT LP/SC 4 was ''high'' based on the majority of hectares in this class undergoing transitions which rated ''high'' for mountain pine beetle succession influence.

The frequency (as proportion of hectares) of each API rating in a polygon class was used to guide the proportion of hectares assigned corresponding levels of succession influence. So, if 5 percent of the hectares in a class were rated as high, the corresponding transitions which related to high activity of mountain pine beetle in lodgepole pine were likely to make up a relatively small proportion of hectares in the polygon class. There were occasions in which a class received a majority of high ratings for a pathogen or insect but had few hectares of transitions that could logically be attributed to that pathogen or insect. The lack of congruent changes was the most important factor in assigning the succession influence. In these cases, although the APIs indicate significant effects were expected, based on actual changes, the transitions were assigned low succession influence values.

Assigning Multiple Pathogens and Insects to Transitions

A single polygon class could have multiple pathogens and insects with high action probabilities. This did not always mean that the high APIs were assigned to the same individual polygons within the class. We used results from analysis of variance (ANOVA) and chi-square tests to determine which of the pathogens and insects tended to have moderate to high probabilities in the same polygons, and which pathogens and insects tended to be independent or exclusive. These results guided decisions on which pathways were likely the results of the combined effects of pathogens and insects and which were probably dominated by a single pathogen or insect. In many cases a particular transition received a succession influence index value of high for one pathogen or insect and much lower values for several others, according to

results of this analysis, which indicated that they tended to occur in the same polygons but only one had high APIs, with a correspondingly appropriate transition occurring.

Assigning Succession Influence Index to Polygon Classes Not Represented in 1975-era Sample Polygons

In ecosection M332a, 64 percent of the 1935 polygon classes, representing 79 percent of hectares in the sample, were also present in the 1975 polygon sample. Most of the polygon classes that were not represented in 1975 data were white pine, ponderosa pine, lodgepole pine or western larch cover types in structure classes 2 or 4 in a variety of habitat type groups. Fortunately, the pine bark beetles that have the highest probable activity in these forest types are not strongly dependent upon habitat types. This allowed us to apply statistics applicable to the cover type and structure combinations based on most similar habitat type groups.

Ecosection M333d was somewhat better represented, with 72 percent of the polygon classes from 1935 (95 percent of hectares) found in the 1975 sample. There were 41 polygon classes that were not found in the 1975 polygon sample; of these, 74.4 percent of the hectares were western white pine types. For polygon classes with large components of western white pine in 1935 that no longer had this species in the forest type in 1975 (with no evidence of tree harvest), white pine blister rust was assumed to have played a dominant role in most transitions. For stands beginning in large-diameter structure classes (3 or 4), mountain pine beetle was assumed to have played a role in most transitions as well (see the results by Schwandt for white pine blister rust and by Kegley for mountain pine beetle in western white pine for further explanation).

For other pathogens and insects, grouping unsampled classes with similar, sampled classes provided estimates of the APIs. For each of the pathogens and insects, the unsampled polygon classes were grouped with sampled classes with the most similar characteristics from the standpoint of the pathogen or insect. Grouping was based on the attributes of stands which were either best correlated or had the highest chi square values when compared with the APIs for the insect or pathogen (see the statistical analysis ecosection by Marsden). For example, root disease severity was most highly correlated with structure class, so all grouping of unsampled polygons took place within the same structure class. Habitat type group was also significantly correlated with root disease severity (RRSV), so grouping was done within habitat type groups as well. Finally, because cover type was also significantly correlated, unsampled cover types were grouped with those having cover types that would function quite similarly from the standpoint of insects and pathogens. A polygon in HT 5/FT DFL /SC 4 would be similar to HT 5/FT DFPP /SC 4 for common root pathogens. (However, this grouping was not used for larch dwarf mistletoe. Instead, HT 5/FT DFL /SC 4 was grouped with HT 5/FT GFL/SC 4 to assign the APIs to the unsampled polygon class.)

SECTION 4: METHODS
Part 3: Oracle Database Management and Statistical Analyses

MANAGING PROJECT ATTRIBUTE DATA

By Stephen Williams and Terri Johnson

Overview

Conducting this project involved a significant amount of data, both spatial and non-spatial. The data represented sampled subcompartments encompassing 12 Northern Region National Forests. For the 1975-era dataset, more than 5,000 stands were analyzed. For the 1935-era dataset, just under 2,000 stands were examined. All attribute data (i.e., non-spatial data) was pulled together in a set of project-designed database schema using Oracle as the relational database managment system (RDBMS). For the attribute data, each stand record included numerous data items, including data items extracted from other existing Oracle database tables, data items extracted from flat files, data items input manually via the structural query language (SQL) "update" command, and data items calculated and then inserted via Oracle's PL*SQL scripts. Gathering data from a diversity of sources and formats in support of the numerous scripts used to analyze and summarize data was a major challenge for this project. This ecosection reviews those challenges both in terms of data collection and data analysis. GIS data challenges are discussed in Section 2, Part 1: GIS Processing and Polygon Classification.

Why Use Oracle?

Oracle is the corporate relational database management system (RDBMS) utilized by the Forest Service and thus utilized by this project to capture, manipulate, analyze, and summarize project attribute data. The Oracle RDBMS is present on all corporately supported Forest Service computer systems, and thus, any data structures and supporting scripts (e.g., PL*SQL scripts and ReportWriter scripts) developed through this project may be easily adapted for use by others on similar projects.

Some benefits of utilizing the Oracle RDBMS versus other options:

- Much of the needed attribute data was already stored in various Oracle database tables.
- Staffs across remote locations could share and access data via the existing FS computing infrastructure.
- Spatial data as represented in Arc/Info coverages could be easily linked to attribute data stored in Oracle tables.
- Other FS employees were available for advice on Oracle procedures needed to transfer or otherwise manipulate attribute data.
- Since all FS sites have access to Oracle, methods, scripts, and data structures developed through this project can be more easily adopted by potential end-users.

Some disadvantages of utilizing the Oracle RDBMS versus other options:

- Oracle is not as user-friendly as some PC-based database software products, and requires fairly strong software engineering skills to use effectively.
- Summary data from this project are difficult to create in an ad-hoc manner by less technically oriented end users using Oracle (although a fairly new product, Discover2000, has potential to overcome this limitation).

Input Data Needs

The principal data needed to support this successional analysis methodology included: stand data for a set of polygons from two time periods, data for deriving stand classification parameters, and data for supporting the insect and pathogen queries.

Data representing two time periods for the same "pieces" of ground was needed in order to examine actual successional changes that occurred over time. A forest survey conducted in the 1975 across the Northern Region National Forests provided one needed set of data. Another forest survey conducted in the 1935 provided the other set of data. Most of the sampled subcompartments from the 1975 dataset had a complimentary dataset from the 1935. Successional change across a 40-year period could thus be examined. As discussed elsewhere, data collection procedures, including the data recorded, varied between the two surveys, so some data processing was necessary in order to match attributes across the two datasets. For example, the classification system used to assign cover or forest type varied between the two datasets, so the classification logic from the 1935 was applied to the 1975 dataset to derive a comparable attribute describing cover type.

Stands were classified into groups based on habitat type, cover or forest type, and structural class in order to examine how a given stand class might change over time to one or more other stand class. Therefore, these classification parameters (habitat type, cover or forest type, and structural class) needed to be captured or derived for the two time period datasets. In the early stages of this project, different classification methods were analyzed, so a few other parameters than described here were captured as well.

The key to highlighting the role of insects and pathogens in succession was to develop metrics--in many cases, these were "action probability indices" derived to indicate a probability and/or likely successional function of a particular insect or pathogen in a stand with given attributes. Many of these indices were determined by examining various stand attributes via Oracle PL*SQL scripts. Thus, the stand attribute data needed to drive these Oracle scripts had to be captured or derived from the 1935 and 1975 source datasets. For this study, only the relevant data for the needed 1975 data was captured in order to support the various insect and pathogen Oracle queries. The indices calculated for various stand classes in the 1975-era dataset were then assigned to stands in the 1935-era dataset that were in the same stand class.

Project Designed Database Structure

With the needed data elements identified as described above, an appropriate set of database schema was designed to support storage and analysis of the project attribute data. The structure described here actually evolved over the life of the project. The "first cut" structure was highly normalized, and for various reasons (including facilitation of end-user querying, as well as lack resources to develop a more robust, multi-regional data structure), this original

structure was denormalized to its present state. Four database tables form the nucleus of this structure (Table 4.1).

Table 4.1. Database tables.

Table Name	Number of Fields
LA_IP_ENDING	43
LA_ENDING_STANDS	23
LA_STARTING_STANDS	25
LA_UNION_STANDS	17

Note the acronym "LA" used as a prefix on many of the project tables, for "Landscape Assessment." Also, tables with "ENDING" in the name referred to tables used to store or manage the 1975 data. Tables with "STARTING" in the name referred to tables used to store or manage the 1935 data. Tables with "UNION" in the name referred to tables used to store or manage attribute data describing the polygons formed when overlaying the 1970's stand polygons with the 1935 stand polygons. This "union" of ArcInfo coverages formed a new coverage with relevant attribute data stored/managed through the set of "UNION" tables.

The LA_IP_ENDING table was a key table used to store the 1975 stand attribute data, including the insect and pathogen successional indices. Many of the scripts used capture data elements from the existing regional Oracle databases where most of the 1975 data was stored, and all of the scripts used to calculate insect and pathogen action probability indices inserted script outputs directly into this table. Some scripts referenced data in this table in order to calculate other derived data. Finally, much of the analysis and summarization needed to support the project worked with data stored in this table (Table 4.2).

Table 4.2. Fields in LA_IP_ENDING.

Field Name	Description
Record Key Fields	
Project_ID	Identifies record by project so as to differentiate different project data
Region_No	Region number such as '01' for the Northern Region
Forest_No	National Forest identifier
Curr_Stand_Id	Stand identifier (in this case, the 1975 stand identifier)
Other Record Identifiers	
Curr_Full_StandID	Stand identifier, including Forest number
Inventory_Date	Date stand data was collected
Baileys_Section	Five-character code describing the appropriate Bailey's ecoregion
Curr_Full_TagID	Identifier used to link to ArcInfo stand polygon

Stand Attributes	
Curr_Area	Stand area, in hectares
Habitat_Type	Habitat type
Habitat_Group	Habitat codes for groups of habityat types
R1_Forest_Cover	Forest type, using R1 definitions
SILC_Cover_Type	Forest type, using SILC definitions
Curr_Cover_Type_1935	Forest type, using 1935 definitions
Curr_Size_Class	Size class code
Curr_Stocking_Level	Stocking level code
Curr_Seral_Stage	Seral stage code
Curr_Structural_Stage	Structural stage code
Cutting_History	One-character code describing cutting history for the stand
Forest_Type	Forest type, as retrieved from TSMRS
Insect and Pathogen Indices	
RR_Severity_IP	Root rot severity rating
WPBR_Hazard_IP	White pine blister rust hazard rating index
WPBR_CURR_IP	White pine blister rust index
DM_DF_Curr_IP	Dwarf mistletoe in Douglas-fir index
DM_WL_Curr_IP	Dwarf mistletoe in western larch index
DM_LP_Curr_IP	Dwarf mistletoe in lodgepole pine index
DFB_Weeding_IP	Douglas-fir beetle weeding index
DFB_Group_IP	Douglas-fir beetle outbreak index
Spruce_Beetle_IP	Spruce beetle index
WSBW_Pattern	Western spruce budworm pattern index
WSBW_Hazard_IP	Western spruce budworm hazard rating index
Decay_ET_IP	Stem decay caused by *Echinodontium tinctorium* index
Decay_LP_IP	Stem decay in LP, WWP, and ES caused by *Phellinus pini*
Decay_Other_IP	Stem decay in larch, PP, DF, and WBP

MPB_LP_IP	Mountain pine beetle in lodgepole pine index
MPB_WP_IP	Mountain pine beetle in white pine index
MPB_PP_IP	Mountain pine beetle in ponderosa pine index
MPB_WBP_IP	Mountain pine beetle in whitebark pine index
LP_Role	Roles by habitat type for lodgepole pine
PP_Role	Roles by habitat type for ponderosa pine
TM_Hazard	Tussock moth hazard rating index

The LA_ENDING_STANDS table is very similar to the above table in that the same 1975 stand records are represented in this table. In fact, if efforts to migrate these data structures into other regions had gone forward, these two tables would probably have been combined into just one table. LA_ENDING_STANDS contained none of the insect and pathogen indices fields, but contained most of the other fields. LA_ENDING_STANDS was used to support some of the spatial querying done through ArcView, was used to support creation of the "union" attribute dataset, and was used to capture key data elements captured through spatial processes such as the Bailey's EcoRegion data and area. This data was later moved into the LA_IP_ENDING table to complete that set of data.

The LA_STARTING_STANDS table is the counterpart table to LA_IP_ENDING in that it was used to store the 1935 stand data. The key fields in this table were similar to LA_IP_ENDING. However, fields representing stand attribute data were different since the 1935 forest survey collected a smaller (as well as slightly different) set of information about a stand. The stand attributes represented in this table included those imported directly from the 1935 data source, as well as structural stage, which was calculated from the other available source data.

Note that the insect and pathogen algorithms executed to determine the various indices for a stand were only run against the 1975 dataset and not the 1935 dataset. As highlighted in other parts of this document, the index values for various stand classes in the 1975 could be inferred to the same stand classes as they existed in the 1935 era.

The LA_UNION_STANDS table contains attribute data for the polygons formed when the 1935 stand polygon coverage was overlaid with the 1975 stand polygon coverage. The purpose of creating this dataset was to support analysis of successional change on polygons between the 1935 and 1975. Thus, beyond data elements to uniquely identify each union polygon, this table contained the 1975 parent stand id, the 1935 parent stand ID, and selected stand attribute data from the parent 1935 and 1975 polygons.

Beyond these four key tables, other tables were created for three specific purposes: working tables used to move data from the original electronic source into one of the four key tables, lookup tables used to store descriptions of some of the data attributes, and summary tables used to store summary data derived from the above four tables.

Working tables included:

LA_ENDING_AREA_LOAD
LA_ENDING_POLYGONS
LA_ENDING_POLYGONS_LOAD

LA_STARTING_AREA_LOAD
LA_STARTING_POLYGONS
LA_STARTING_POLYGONS_LOAD
LA_UNION_POLYGONS
LA_UNION_POLYGONS_LOAD

Generally, data passed through one or more of these tables on its way from the original electronic source into one of the four key tables described previously. These tables were used to both initially store data in the database, transform some data elements into one or more data elements needed for the project, and perform edit checking prior to storing in the main table used by the project for analysis. For example, as 1935 data for a particular National Forest was brought in, records were checked for duplicate stand identifiers, and data elements (such as structural stage) were calculated in these working tables prior to inserting the records into LA_STARTING_STANDS.

Lookup tables included:

AGE_CLASSES
COVER_TYPES_1935
EXCEPTIONS
LA_PROJECTS
SPECIES_COMPOSITION_STATUS
STOCKING_LEVELS
STRUCTURAL_STAGES

These tables generally contain descriptive data for various stand attribute codes used in the main tables. For example, structural stage is stored as codes 1 through 4 in the LA_ENDING_STANDS table. The lookup table STRUCTURAL_STAGES contains four records, each of which contain a description field describing what these codes mean.

Summary tables included:

LA_IP_REPORT
LA_TRANSITION_RPT

Because generation of summary data is a lengthy process, these tables were created to store summary outputs so that the user could generate summary data once and then reuse this summary information via further querying and sorting. This eliminates the need to execute a summary routine every time the user needs to access the same set of summary data.

The LA_IP_REPORT table contains summary records output from a PL*SQL script that groups the 1975 stand records by Bailey's ecosection, habitat type group, structural class, and forest type. Each of these groups is stored as a record in LA_IP_REPORT. The additional fields in this table describe the number of stand records in the group, the number of hectares the group represents, the average, minimum value, and maximum value for each numeric insect or pathogen index, and the frequency distribution for each discrete insect or pathogen index. For example, one record shows there are five 1975 stand records in Bailey's ecosection M332a in which the habitat type group was "4," the forest type was "DFGF," and the structural class was "4." These five records totaled 250 hectares. The average root rot severity rating for these stands was 3.2, the minimum rating was 2, and the maximum was 5. Simular statistics exist for other numeric indices. For the Mountain Pine Beetle in Lodgepole Pine indices, the record has

fields showing that 20 percent of the hectares for this group had an index value of 0, 60 percent had a value of L, 10 percent had a value of M, and 10 percent had a value of H. Simular statistics exist for other discrete insect or pathogen indices. To capture all of this summary data for each record obviously required many fields: this table has more than 100 fields. The data stored in this table can be further organized/sorted/queried to support a variety of needs via products such as MS Access. End-users may pull the data out of this table into other software such as Paradox or Excel as desired.

The LA_TRANSITION_RPT table contains summary records output from a PL*SQL script that groups the union polygon records (i.e., the records created by overlaying the 1935-era stand polygons with the 1975 stand polygons) into groups as in LA_IP_REPORT, but further subdivides these groups according to how they changed from the 1935 to the 1975. Table 4.3 shows two examples of possible records in this table:

Table 4.3. Possible records in LA_TRANSITION_RPT.

Field	Record 1	Record 2
Number records in group	3	4
Bailey's Ecosection	M332A	M332A
Habitat Type Group	3	3
1935 Condition		
Start Forest or Cover Ttype	PPDF	PPDF
Start Structure Class	2	2
Total hectares start group	1216	1216
1975 Condition		
End Forest or Cover Type	DFGF	PPDF
End Structure Class	4	2
Total area in this pathway	364	852
Calculated probability of transition	.3	.7

Other fields follow the above that were used by various project team members to support particular analysis needs.

In the above example, these two records depict that 1935 stands in the group defined by Bailey's ecosection M332a, habitat type group 3, forest type PPDF, structure class 2 transitioned to either forest type DFGF, structure class 4 or to forest type PPDF, structure class 2 by 1975. Specifically, 364 hectares (30 percent) of the area transitioned through one successional pathway, while 852 hectares (70 percent) transitioned through a different pathway.

Database Views

For convenience, a few Oracle Views were created to access needed data that was stored in more than one of the project tables described above. A view is essentially a stored select statement that is established to automatically select out specific records and columns from one or more tables. One view was LA_UNION_STANDS_DATA, which was used to view cover type and structure class data for both the 1935 and 1975 data. This view references both the LA_STARTING_STANDS and LA_ENDING_STANDS tables in order to extract the needed data.

Data Capture Issues

Moving data from its original source to one or more of the described Oracle tables was fairly complicated. Data came from a variety of sources. Most of the required 1975 data resided in either the R1 Edit or TSMRS (timber stand management record system) databases and in two Northern Region-maintained databases. However, some 1975 data was calculated through manipulation of this source data or was input from non-Oracle sources: one example is the root rot severity index, which was determined through photointerpretation, recorded on hardcopy, input into a temporary table using a simple data entry utility, and then input in LA_IP_ENDING via the SQL "update" command. The original source of the 1935 attribute data was handwritten figures shown on hardcopy maps. Within the Northern Region, future users of this methodology will no doubt need to manage all of these data capture situations. Users in other Regions will likely deal with other source data formats and databases.

The R1 Edit database contained much of the stand attribute data needed for the 1975 sampled subcompartments. R1 Edit consists of a series of tables to store survey data for various forest surveys conducted over time in the Northern Region. For this project, the forest survey of interest (i.e., the 1975 data) was identified as "survey type 12"; "12" being the identifier on the database records. R1 Edit includes its own interface for querying and extracting records. Using the R1 Edit system, stand-level attribute data needed for this project was gathered into a R1 Edit stand summary table called DBH_SUMMARY. Note, data is generally kept as plot and tree record data in various R1 Edit tables and must be summarized to the stand-level via R1 Edit utilities. The summary data is created and stored as needed in DBH_SUMMARY. Data in DBH_SUMMARY was transferred into LA_IP_ENDING using PL*SQL scripts. Some data in DBH_SUMMARY was not transferred into LA_IP_ENDING but was used in calculations in order to derive the needed data elements for stands represented in LA_IP_ENDING. Examples of DBH_SUMMARY data elements used in calculations or transferred to LA_IP_ENDING include: Trees_per_acre_gt3, Basal_area, Average_age, and Averge_dbh. By reviewing the discussion of various insect and pathogen change agents in this document, one can determine the stand attributes referenced in order to calculate various insect and pathogen action probability indices.

The TSMRS database contained a few important stand attributes not stored in R1 Edit, mainly habitat type and forest type. A simple SQL script (composed of insert and update commands) was used to pull the needed data from TSMRS into LA_IP_ENDING.

As noted, some of the needed data stored in LA_IP_ENDING came from neither R1 Edit or TSMRS. The 5-character code identifying Bailey's ecoregion information for a stand was derived using ArcView by overlaying the Bailey's ecoregion theme with our 1975 stand polygon theme so that this information could be joined to the stand polygon. Thus relevant stand records

with the associated Bailey's code could then be output as a comma-delimited flat file. Included with this flat file was the area of each stand polygon and the tagID used in ArcView to uniquely identify stand polygons. This information was then imported into LA_IP_ENDING via a SQL*Loader script through the LA_ENDING_AREA_LOAD intermediate table.

Some of the stand attribute data in LA_IP_ENDING, such as structural stage, and most of the insect and pathogen indices were calculated, and the result inserted into the table via a variety of PL*SQL scripts. These scripts referenced other fields in LA_IP_ENDING or fields in DBH_SUMMARY in order to derive the needed value (see specific insect or pathogen discussions in this document for more detail on the logic of these scripts).

Four change agent measures, namely the root rot severity index, western spruce budworm pattern (WSBW_pattern), Ponderosa Pine role (pp_role), and Lodgepole Pine role (lp_role) did not utilize PL*SQL scripts. Assigning a root rot severity index value to a stand was accomplished through photo intrepretation, and the assigned value inserted into the LA_IP_ENDING table. Assignment of the WSBW_pattern code was done via an entomologist, through professional judgement, assigning a pattern code generally to all stands within a given forest, and then inserting this code in the Oracle table for those stands via the Oracle update command. The pp_role and lp_role indices were handled in a similar manner.

Attribute data describing 1935 stands consisted of a series of codes handwritten on the survey maps. These data were captured initially by the digitizer by keying this information, exactly as it appeared, into a common delimited ASCII file using a PC-based database product. Early in the project, a SQL*Loader routine was run to import this data into an intermediate Oracle table for further processing before the data was inserted into its final resting place - LA_STARTING_STANDS. As the data for each subsequent forest was processed, the lack of consistency in coding methods from one forest to another, made it apparent that one could never write an automated routine to correctly interpret these codes in order to derive the needed attribute data as represented in LA_STARTING_STANDS. One could easily interpret what the person (i.e., the field staffer who collected the information) meant by looking at the codes, but subtle variations in coding methods such as the use of commas, hyphens, and spaces made it essentially impossible to write a program to interpret every variation in these recordings. Increasingly complex PL*SQL scripts that attempted to interpret this varying data across forests, were later simplified by requiring that the input data adhere to certain formatting standards. Although not technically savy, but certainly efficient, data as it existed in the ASCII files was edited with a text editor to make sure it fit those format standards before it was imported into the Oracle tables using a SQL*Loader script. Once in the initial Oracle table, a series of PL*SQL scripts were run to derive such attributes as structural stage and age class based on the known attributes.

Data Management Scripts

Several dozen Oracle SQL and PL*SQL scripts were written to move, edit, and summarize data. Many of these scripts were referenced in the text of the above sections. The type of scripts developed can be summarized as follows:

- Database setup scripts: DDL (data definition language) scripts to initially create the needed database objects; tables, views, constraints, etc.
- Data loader scripts: fairly simple SQL*Loader scripts used to import flat file data into Oracle tables. Used to bring in 1935-era data and data derived through ArcView analyses.

- Data editing, data preparation scripts: used to check for data problems such a duplicate records and invalid values prior to inserting data into the target tables (i.e., LA_ENDING_STANDS, LA_STARTING_STANDS, LA_UNION_STANDS). These same scripts included logic to derive or extract data elements from other tables. For example, derivation of structural stage codes were calculated within one such script prior to inserting these codes into the final table. For example, scripts were written to extract data from R1 Edit tables and insert this data into LA_IP_ENDING.
- Insect and Pathogen indice scripts: the series of SQL scripts used to derive the insect and pathogen indices.
- Print utility scripts: SQL and PL*SQL scripts used to print hardcopy reports such as error reports, and various summaries that were useful for checking data to determine if the data was valid or if the data was migrated to a table as expected.
- Summarization scripts: SQL and PL*SQL scripts used to calculate final summaries containing weighted averages, frequencies, etc. for defined stand classes.

Opportunities

The primary objective of this project was to define a methodology for analyzing the role of insect and pathogens in succession. Since the methodology did not exist, this exercise included a fair amount of trial and error. Future users of this methodology should consider the following so as to take advantage of what was learned from this project:

The output products should be clearly defined at the beginning of the project because these products largely dictate specific data needs, data processing needs, and in general, user requirements. For example, the type of reports needed, the frequency of those reports, and the required flexibility to configure those reports will determine how one chooses to manage the data. In this project, required flexibility has encouraged the project team to consider a commercial product, Discover2000, as a reporting and browsing tool as opposed to using customized reporting scripts such as PL*SQL scripts. The time required to develop customized scripts that are flexible is extensive, and thus, purchasing a commercial product may be the more time- and cost-efficient option.

Once output products are defined, consider the data needed to produce those products. The availability of the data, the format of the data initially, and variation in format and availability across different locations can dramatically affect the feasibility of the project and the timeline. On this project, extensive time was spent collecting data from multiple locations, and extensive time was spent "cleaning" data that came in different formats from these different locations. Careful consideration of these issues is needed in order to establish realistic timelines.

Knowing up-front the outputs required, the data needed, and how users will want to access that data will allow the project team to define the best data structure (set of tables) up front. Having to change the data structure late in the project can be time-consuming. Particular issues that were challenging for this project included how to manage and maintain the relationship between the spatial data as represented by ArcInfo coverages and attribute data as represented in Oracle tables. Another issue was how to promote end-user self sufficiency in generating reports from a complex data structure versus simplifying the data structure at the expense of providing a robust data structure that could be useful beyond the Northern Region and on other projects.

STATISTICAL ANALYSES

By Michael Marsden

The statistical analyses of the data was computed within each ecosection using the model structure as fixed factors in the analyses. The insect and disease APIs at the stand level were the subject of these analyses. For indices that were discrete classes a series of simple chi-square analyses were computed. For nominal valued indices, the more robust Analysis of Variance (ANOVA) method was used. Here, the type III sum of squares is tested for each main effect and interaction because the experiment is not a balanced factorial. Each main effect or interaction is first adjusted for all other sources of variation then tested against the error mean square. This is why, in some analyses the overall model is significant, but none of the individual sources of variation are significant (example: WPBRPROB, the probability of action index for white pine blister rust, in ecosection M332a.) It should also be noted that when the total model accounts for more of the variation in the data, more of the individual sources of variation are found to be significant. This follows because the smaller the mean square (the denominator in the F-ratio) the larger the F-statistic.

The statistical analyses for ecosection M332a are presented in two parts. The first part is the analyses using the forest types with the 1975 inventory data.The second part is the same set of analyses using the cover types (Table 2.5) with the 1975 inventory data. Site class and structure class are the same for both analyses.

Ecosection M332a : Statistical Analysis of Relationships Between APIs and Habitat Type Group, Forest Type, and Structure Class

Analysis of variance of APIs with nominal values

The first variable considered for analyses was RRSEVER, the root disease severity code. This variable can take on the values 0 through 9, and is considered a nominal variable; hence, we used the analysis of variance procedure to evaluate how well the three ecological variables explained the variation found in the root disease severity data.

In the tables that follow the values for each of the three independent variables are given (Table 4.4). This is followed by the analysis of variance table for the dependent variable, RRSEVER (Table 4.5). The three factors used in these analyses were; HAB_GR, FOR_TYP, and STRU_CL. The observations are weighted by the area of the sample stands. The analyses were computed using SAS with Type III Sum of Squares. For these analyses, each factor or source of variation is first adjusted for all others in the table before testing. The statistical model accounted for more the 75 percent of the variation in the variable RRSEVER for 349 samples, as indicated by the R-Square of 0.766. Factors and interactions of factors are tested individually.

The most significant factor in the analysis is STRU_CL, the structure class (Table 4.5). We can conclude that the variable RRSEVER is not the same for the four structure classes. The probability of getting such a high F-statistic by chance when RRSEVER is the same among structure classes is extremely small: 0.0002. Next in significance is FOR_TYP. Here there are 56 levels and we can conclude that the variable RRSEVER is different from the sample average for sum levels of this factor, i.e. cover types. The factor HAB_GR, Site Class, and the interaction FOR_TYP*STRU_CL also have F-statistics high enough for us to doubt that RRSEVER is equal

with regard to these sources of variation. The interaction FOR_TYP*STRU_CL is adjusted for both the main effects STRU_CL and FOR_TYP before these test statistics are computed.

Table 4.4: General linear lodels procedure for factors including habitat type group, forest type and structure class; class-level information.

Variable Abbreviation and Type	Number of Levels	Values in Data
HAB_GR, habitat type group	12	1, 2, 3, 4 ,5, 6, 7, 8, 9, 10, 11, 15
FOR_TYP, forest type	56	AF, AFC DF, AFC GF, AFDF, AFDFGF, AFDFL, AFDFLP, AFDFMH, AFDFS, AFGF, AFGFS, AFL S, AFLP, AFLPS, AFLPWB, AFS, AFS WB, AFWB, C, C DF, C DFGF, C GF, C GFPP, DF, DFGF, DFGFL, DFGFLP, DFGFPP, DF-GFS, DFL, DFL LP, DFLP, DFLPPP, DFLPS, DFMHS, DFPP, DFPPS, DFS, GF, GFL, GFL LP, GFLP, GFLPPP, GFMHS, GFPP, GFS, L, L S, LP, LPPP, MH, NF, PP, S, WB, Y
STRU_CL, current structure class	4	1, 2, 3, 4

Number of observations in data set = 451; due to missing values, only 429 observations were used in this analysis.

Table 4.5: General linear models procedure for dependent variable RRSEVER, weighted by area, with factors including habitat type group, forest type and structure class.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob > F
Model	199	15801.1204	79.4026	3.31	0.0001
Error	229	5497.3483	240058		
Corrected Total	428	21298.4687			

R-square	C.V.	Root MSE	RRSEVER Mean
0.741890	130.6556	4.89958038	3.74999658

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	Prob >F
HAB_GR	10	549.6946	59.4694	2.48	0.0078
FOR_TYP	53	1934.9390	36.5082	1.52	0.0193
HAB_GR*FOR_TYP	40	1118.1039	27.9525	1.16	0.2437
STRU_CL	3	295.7892	73.9473	3.08	0.0170

HAB_GR*STRU_CL	20	698.4192	34.9209	1.45	0.0993
FOR_TYP*STRU_CL	40	975.1183	24.3779	1.02	0.4521
HAB_GR*FOR_TYP* STRU_CL	8	169.8574	21.2321	0.88	0.5303

In addition to RRSEVER, the following API variables were subject to analysis of variance: WPBRHAZ, WPBRPROB, DMDFPROB, DMWLPROB, DMLPPROB, WSBWHAZ, DECAYET, DECAYLP, and DECAYOT (Table 4.6). Except for WPBRPROB, the analyses found the factors significant (with $Pr > F < 0.100$) either as main effects or as interactions. Therefore, using separate estimates of the API values by factor combinations is justified. This does not mean that some combinations of factor levels can not be combined.

Table 4.6: Summary of results of general linear models procedure using dependent variable action probability indices, weighted by area, for factors including habitat type group, forest type and structure class.

Action Probability Index	Code	%Var. ANV	Factors (most significant to least)
Root disease	RRSEVER	0.742	HAB_GR, STRU_CL, FOR_TYP,HAB_GR*STRU_CL
White pine blister rust hazard	WPBRHAZ	.990	HAB_GR, FOR_TYP, HAB_GR*FOR_TYP
White pine blister rust probability	WPBRPROB	.151	No significant factors
Douglas-fir dwarf mistletoe	DMDFPROB	.876	FOR_TYP, FOR_TYP*STRU_CL, HAB_GR*FOR_TYP, HAB_GR
Western larch dwarf mistletoe	DMWLPROB	.760	FOR_TYP, HAB_GR*FOR_TYP*STRU_CL
Lodgepole pine dwarf mistletoe	DMLPPROB	.809	FOR_TYP
Western spruce budworm	WSPWHAZ	.625	FOR_TYP*STRU_CL, STRU_CL
Echinodontium stem decay	DECAYET	.764	FOR_TYP, FOR_TYP*STRU_CL
Phellinus pini stem decay	DECAYLP	.790	FOR_TYP, HAB_GR*FOR_TYP, FOR_TYP*STRU_CL
Other stem decay	DECAYOT	.810	FOR_TYP, HAB_GR

Chi-square tests for APIs with discrete classes

The several APIs had only discrete classes and were subject to simple chi-square test aginst each of the three factors. The factor HAB_GR (Table 4.7) was highly significant with respect to all variables except Douglas-fir beetle group API and mountain pine beetle in white-bark pine and western white pine API. Factors FOR_TYP (Table 4.8) and STRU_CL (Table 4.9) were highly significant with all variables.

Table 4.7: Chi-square analysis of variables with discrete classes for FACTOR = HAB_GR.

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	14.34	22	0.89
Douglas-fir beetle single tree action	373.61	33	0.00
Mountain pine beetle in lodgepole pine	149.64	33	0.00
Mountain pine beetle in ponderosa pine	184.15	33	0.00
Mountain pine beetle in whitebark pine	26.09	33	0.80
Mountain pine beetle in western white pine	25.35	22	0.28
Spruce beetle	127.34	33	0.00
Western spruce budworm	103.10	33	0.00

Table 4.8: Chi-square analysis of variables with discrete classes for FACTOR = FOR_TYP

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	172.38	112	0.00
Douglas-fir beetle single tree action	508.88	168	0.00
Mountain pine beetle in lodgepole pine	489.00	168	0.00
Mountain pine beetle in ponderosa pine	393.81	168	0.00
Mountain pine beetle in whitebark pine	351.52	168	0.00

Mountain pine beetle in western white pine	169.80	112	0.00
Spruce beetle	430.61	168	0.00
Western spruce budworm	667.94	168	0.00

Table 4.9: Chi-square analysis of variables with discrete classes for FACTOR = STRU_CL.

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	56.87	8	0.00
Douglas-fir beetle single tree action	95.15	12	0.00
Mountain pine beetle in lodgepole pine	118.95	12	0.00
Mountain pine beetle in ponderosa pine	97.81	12	0.00
Mountain pine beetle in whitebark pine	10.80	12	0.00
Mountain pine beetle in western white pine	23.35	8	0.00
Spruce beetle	47.00	12	0.00
Western spruce budworm	72.80	4	0.00

Ecosection M332a: Statistical Analysis of Relationships Between APIs and Habitat Type Group, Cover Type, and Structure Classes

Analysis of variance for APIs with nominal values

Using COV_TYP, the 1935 cover type, in place of FOR_TYP, the anayses of variance were recomputed (Table 4.10). The complete table is presented for RRSEVER only (Table 4.11). A summary is given for all ten variables.

Table 4.10: General linear models procedure for factors including habitat type group, cover type, and structure class; class-level information.

Variable Abbreviation and Type	Number of Levels	Values in Data
HAB_GR, Habitat type group	11	1, 2, 3, 4 ,5, 6, 7, 8, 9, 10, 11
COV_TYP, Cover type	13	1, 2, 2.8, 3, 5, 5.2, 6, 7, 8, 9, 9.1, 9.2, 11, 19
STRU_CL, Structure class	4	1, 2, 3, 4

Number of observations in data set = 451; due to missing values, only 429 observations were used in this analysis.

Table 4.11: General linear models procedure for dependent variable RRSEVER, weighted by area, for factors including habitat type group, cover type, and structure class.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Prob > F
Model	133	13386.4509	100.6500	3.75	0.0001
Error	295	7912.0177	26.8203		
Corrected Total	428	21298.4687			

R-square	C.V.	Root MSE	RRSEVER Mean
0.628517	138.1026	5.17884150	3.74999658

Source	Degrees of Freedom	Type III SS	Mean Square	F Value	Prob >F
HAB_GR	11	1111.4172	101.0379	3.77	0.0001
COV_TYP	12	228.9801	19.0816	0.71	0.7401
HAB_GR*COV_TYP	34	831.7229	24.4624	0.91	0.6126
STRU_CL	3	50.3910	16.7970	0.63	0.5985
HAB_GR*STRU_CL	19	864.7393	45.5125	1.70	0.0358
COV_TYP*STRU_CL	22	548.4986	24.9317	0.93	0.5558
HAB_GR*COV_TYP*STRU_CL	17	263.7420	15.5142	0.58	0.9070

For RRSEVER, the factor HAB_GR and the interaction HAB_GR*STRU_CL are significant. COV_TYP is not significant in contrast to the factor it replaced, FOR_TYP, perhaps

because it has only 12 degrees of freedom or 13 effective groups, while FOR_TYP had 54. The error mean square increased from 24.0059 to 26.8204, resulting in fewer lower significant levels for other factors in the analysis.

A general summary is given for the other nine variables (Table 4.12). Except for WP-BRPROB the analyses found the factors significant either as main effects or as interactions. Therefore using separate estimates of the API values by factor combinations is justified. This does not mean that some combinations of factor levels can not be combined.

Table 4.12: Summary of results of general linear models procedure using the dependent variable action probability indices, weighted by area, for factors including habitat type group, cover type and structure class.

Action Probability Index	Code	%Var. ANV	Factors (most significant to least)
Root disease	RRSEVER	0.628	HAB_GR, HAB_GR*STRU_CL
White pine blister rust hazard	WPBRHAZ	0.982	HAB_GR
White pine blister rust probability	WPBRPROB	1.000	COV_TYP, HAB_GR
Douglas-fir dwarf mistletoe	DMDFPROB	0.744	COV_TYP
Western larch dwarf mistletoe	DMWLPROB	0.614	HAB_GR*STRU_CL, COV_TYP
Lodgepole pine dwarf mistletoe	DMLPPROB	0.775	COV_TYP
Western spruce budworm	WSPWHAZ	.490	COV_TYP
Echinodontium stem decay	DECAYET	.683	COV_TYP, COV_TYP* STRU_CL
Phellinus pini stem decay	DECAYLP	.693	COV_TYP
Other stem decay	DECAYOT	.722	COV_TYP, STRU_CL, HAB_GR*COV_TYP

Chi-square tests for APIs with discrete classes

The chi-square tests using COV_TYP, was calculated for the discrete classes of APIs (Table 4.13). A significant chi-square value indicates that, in each case, the frequencies of the values of that variable was not the same for all cover types. The tests with respect to habitat type groups and structure classes were presented in Part 1.

Table 4.13: Chi-square analysis of variables with discrete classes for FACTOR = COV_TYP.

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	84.44	26	0.00
Douglas-fir beetle single tree action	268.88	39	0.00
Mountain pine beetle in lodgepole pine	335.38	39	0.00
Mountain pine beetle in ponderosa pine	426.75	39	0.00
Mountain pine beetle in whitebark pine	30.01	39	0.85
Mountain pine beetle in western white pine	158.17	26	0.00
Spruce beetle	231.62	39	0.00
Western spruce budworm	411.15	39	0.00

Ecosection M333d: Statistical Analysis of Relationships Between APIs and Habitat Type Group, Forest Type, and Structure Classes

Analysis of variance for APIs with nominal values

Since parts 3 and 4 closely follow the pattern of parts 1 and 2, only the summary for the analyses of variance will be given.

Except for WSBWHAZ, the analyses found the factors significant either as main effects or as interactions(Table 4.14). Therefore, using separate estimates of the API values by factor combinations is justified. This does not mean that some combinations of factor levels can not be combined.

Table 4.14: Summary of results of general linear models procedure using the dependent variable action probability indices, weighted by area, for factors including habitat type group, cover type, and structure class.

Action Probability Index	Code	%Var. ANV	Factors (most significant to least)
Root disease	RRSEVER	0.577	FOR_TYP, FOR_TYP*STRU_CL, HAB_GR, STRU_CL
White pine blister rust hazard	WPBRHAZ	0.999	HAB_GR
White pine blister rust probility	WPBRPROB	0.770	FOR_TYP, FOR_TYP*STRU_CL, HAB_GR*FOR_TYP
Douglas-fir dwarf mistletoe	DMDFPROB	0.756	FOR_TYP, HAB_GR, HAB_GR*FOR_TYP
Western larch dwarf mistletoe	DMWLPROB	0.706	FOR_TYP, FOR_TYP*STRU_CL, STRU_CL
Lodgepole pine dwarf mistletoe	DMLPPROB	0.869	FOR_TYP, HAB_GR*FOR_TYP, FOR_TYP*STRU_CL
Western spruce budworm	WSPWHAZ	0.533	No significant factors or interactions
Echinodontium stem decay	DECAYET	0.747	FOR_TYP, FOR_TYP*STRU_CL
Phellinus pini stem decay	DECAYLP	0.754	FOR_TYP, HAB_GR*FOR_TYP, FOR_TYP*STRU_CL, HAB_GR*FOR_TYP*STRU_CL
Other stem decay	DECAYOT	0.768	FOR_TYP, FOR_TYP*STRU_CL, STRU_CL, FOR_TYP*STRU_CL

Chi-square tests for APIs with discrete values

The discrete classed valued APIs were subject to simple chi-square test aginst each of the three factors. The factor HAB_GRP (Table 4.15) was highly significant with respect to all variables. Factor FOR_TYP (Table 4.16) was highly significant with respect to all variables except the Douglas-fir beetle group API. STRU_CL (Table 4.17) was highly significant with all variables.

Table 4.15: Chi-square analysis of variables with discrete classes for FACTOR = HAB_GRP.

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	73.45	22	0.00
Douglas-fir beetle single tree action	776.87	33	0.00
Mountain pine beetle in lodgepole pine	190.07	33	0.00
Mountain pine beetle in ponderosa pine	252.90	33	0.00
Mountain pine beetle in whitebark pine	--	--	--
Mountain pine beetle in western white pine	136.04	33	0.00
Spruce beetle	158.34	22	0.00
Western spruce budworm	484.74	22	0.00

Table 4.16: Chi-square analysis of variables with discrete classes for FACTOR = FOR_TYP

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	225.85	254	0.90
Douglas-fir beetle single tree action	1110.08	381	0.00
Mountain pine beetle in lodgepole pine	1467.06	381	0.00
Mountain pine beetle in ponderosa pine	1119.77	381	0.00
Mountain pine beetle in whitebark pine	--	--	--
Mountain pine beetle in western white pine	548.63	381	0.00
Spruce beetle	880.36	254	0.00
Western spruce budworm	630.98	254	0.00

Table 4.17: Chi-square analysis of variables with discrete classes for FACTOR = STRU_CL .

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	94.57	8	0.00
Douglas-fir beetle single tree action	219.40	12	0.00
Mountain pine beetle in lodgepole pine	115.64	12	0.00
Mountain pine beetle in ponderosa pine	40.02	12	0.00
Mountain pine beetle in whitebark pine	--	--	--
Mountain pine beetle in western white pine	468.60	12	0.00
Spruce beetle	63.06	8	0.00
Western spruce budworm	45.42	8	0.00

Ecosection M333d Statistical Analysis of Relationships Between APIs and Habitat Type Group, Cover Type, and Structure Classes

Analysis of variance for APIs with nominal values

Except for the western spruce budworm API, the analyses found the factors significant either as main effects or as interactions (Table 4.18). Therefore, using separate estimates of the API values by factor combinations is justified. This does not mean that some combinations of factor levels can not be combined.

Table 4.18: Summary of results of general linear models procedure using the dependent variable action probability indices, weighted by area, for factors including habitat type group, cover type, and structure class.

Action Probability Index	Code	%Var. ANV	Factors (most significant to least)
Root disease	RRSEVER	0.324	COV_TYP
White pine blister rust hazard	WPBRHAZ	0.999	HAB_GR*COV_TYP, HAB_GR*COV_TYP*STRU_CL
White pine blister rust probility	WPBRPROB	0.743	COV_TYP, HAB_GR
Douglas-fir dwarf mistletoe	DMDFPROB	0.576	COV_TYP, HAB_GR*COV_TYP*STRU_CL, HAB_GR
Western larch dwarf mistletoe	DMWLPROB	0.353	COV_TYP
Lodgepole pine dwarf mistletoe	DMLPPROB	0.726	COV_TYP, HAB_GR*COV_TYP, HAB_GR*COV_TYP*STRU_CL
Western spruce budworm	WSPWHAZ	0.412	No significant factors or interactions
Echinodontium stem decay	DECAYET	0.482	COV_TYP, HAB_GR, HAB_GR*STRU_CL
Phellinus pini stem decay	DECAYLP	0.520	COV_TYP
Other stem decay	DECAYOT	0.584	COV_TYP, HAB_GR*STRU_CL

Chi-square tests for APIs with discrete values

The discrete classed valued APIs were subject to simple Chi-square test. The factor COV_TYP (Table 4.19) was highly significant with respect to all variables.

Table 4.19: Chi-square analysis of variables with discrete classes for FACTOR = COV_TYP.

API	Chi-square	Degrees of Freedom	P-value
Douglas-fir beetle group action	114.51	28	0.00
Douglas-fir beetle single tree action	495.94	42	0.00
Mountain pine beetle in lodgepole pine	732.20	42	0.00
Mountain pine beetle in ponderosa pine	778.03	42	0.00
Mountain pine beetle in whitebark pine			
Mountain pine beetle in western white pine	300.48	42	0.00
Spruce beetle	255.20	28	0.00
Western spruce budworm	313.25	28	0.00

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Hagle, S.; J. Schwandt; T. Johnson; S. Kegley; C. Bell Randall; J. Taylor; I. B. Lockman; N. Sturdevant; M. Marsden. 2000. Successional Functions of Pathogens and Insects; Ecoregion Sections M332a and M333d in Northern Idaho and Western Montana. Volume 2: Results and Conclusions. Region 1 FHP Report No. 00-11. Missoula, MT: USDA Forest Service, State and Private Forestry, Cooperative Forestry and Forest Health Protection, Northern Region. 283 p.

Byler, J. and S. Hagle. 2000. Successional Functions of Pathogens and Insects; Ecoregion Sections M332a and M333d in Northern Idaho and Western Montana: Summary. Region 1 FHP Report 00-09. Missoula, MT: USDA Forest Service, State and Private Forestry, Cooperative Forestry and Forest Health Protection, Northern Region. 39 p.

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